Naval Submarine Medical Research Laboratory

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J. R. SIMS, D. M. FOTHERGILL, and C. L. SCHLICHTING

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EXECUTIVE SUMMARY

Study Objective

Physical exertion is an inherent element in many Special Operations Forces' (SOF) missions. It was hypothesized that a SOF unit following a prolonged submarine deployment might have a decrement in a variety of physical tasks that require aerobic endurance, anaerobic bursts or physical strength. This study was conducted to document how mission-related performance of SEAL Team One is affected following a long submarine deployment on SSN 642 Kamehameha.

Methods

A total of 22 individuals participated over 66 days which included 33 days of deployment for the SEAL Team (DST) and 53 days of deployment for the submariner control group (SCG). Another control group of 9 members from a non-deployed SEAL Team (NDST) was studied over the same time period as the deployed SEAL Team. All subjects performed cognitive and physical test batteries immediately before and after deployment. Variables believed to influence mission-related performance such as activity levels, medical symptoms, mood levels, dietary intake, and submarine atmosphere were also monitored over the entire length of the study.

Results

Results showed between a 3% and 11% (± 95% confidence limits) decrease in the distance ran during a 12-min maximal effort run for the DST after deployment ($p<0.002$). The DST also had between a 4% and 15% (± 95% confidence limits) decrease in the number of steps climbed during a 1-min step test after deployment ($p<0.006$). The DST reported exercising 70% less time than the NDST over the entire time of the study ($p<0.01$). There was no significant change in any measures of the DST between pre-deployment and post-deployment for maximum grip strength, grip strength endurance, manual dexterity, pull-ups, cognition or body weight ($p>0.05$). There were significant increases in medical complaints for sinuses, headaches, backaches, constipation, and cuts/sores during the deployment for the DST ($p<0.05$). Deployment had a significant negative affect on mood scores in 9 of the 13 parameters measured for the DST ($p<0.05$). Meanwhile there was no change in mood scores for the NDST. In contrast to the DST the SCG showed significant improvements in running performance ($p<0.01$) and step test performance ($p<0.05$) following deployment. The improved performance by the SCG is likely a result of a significant practice effect due to the fact that the SCG were only able to perform the physical test battery once prior to deployment.

Conclusions

In conclusion, a 33-day deployment on a converted ballistic-missile submarine, resulted in statistically significant decreases in aerobic and anaerobic performance, as well as increases in medical complaints in members of this deployed SEAL Team. It is possible that some of the medical complaints may impact Dry Deck Shelter operations (e.g. increase in sinus problems). It is unknown to what level the observed degree of deconditioning will impact the SEALs performance during an actual mission; however, it can be inferred from the results that mission-related performance will be most impacted when extended periods of physical exertion and short high intensity activity is required. It should be borne in mind that some of the observed decrements in performance of the DST may have been due to asynchrony of circadian rhythms and the effects of jet-lag resulting from their air flight travel from Korea to Hawaii immediately before conducting the post-deployment tests.

INTRODUCTION

Physical exertion is an inherent element in many Special Operations Forces' (SOF) missions. Troops perform a variety of demanding tasks that require aerobic endurance, anaerobic bursts and physical strength. Examples of the physical demands of Sea-Air-Land (SEAL) operations are described in Prusaczyk et al., (1995) and include swimming/diving, running, long load-bearing hikes, climbing, and piloting SEAL Delivery Vehicles (SDVs). SOFs typically maintain intense physical training regimens to perform these tasks on real-world missions (Barnes and Strauss 1986; Prusaczyk et al., 1991, 1994). Concern has been voiced that long transits with SOF units on board submarines results in a degradation of their mission-related performance. Potential factors that might contribute to poor mission-related performance are physical inactivity, alterations in exercise routines, changes in diet or sleep patterns, fluctuations of emotional or cognitive states, perturbations of submarine atmosphere and increases of medical ailments. Currently, it is uncertain that a decrement in performance exists and if it does, what impact any decrement has on operations. We conducted a controlled observational study to document decrements in mission-related performance and identify those factors that may have the largest influence on the identified decrements.

METHODS

The Committee for Protection of Human Subjects at the Naval Submarine Medical Research Laboratory, Groton, Connecticut and Naval Medical Research and Development Command, Bethesda, Maryland approved the study. All subjects were recruited from SDV Team One and the USS Kamehameha SSN 642 in Pearl Harbor, Hawaii. All subjects were informed volunteers. A total of 31 subjects participated, 10 members in the deployed SEAL Team (DST), 9 members in the non-deployed SEAL team (NDST), and 12 members in the submariner control group (SCG). No subject withdrew from the study. The data below were collected on all three groups over a two-week period prior to submarine deployment for DST and SCG. The DST underwent a 33-day deployment then returned to Pearl Harbor by airplane and performed post-deployment tests. The NDST performed all "post-deployment" tests two days prior to the return of the DST. Post-deployment testing on the SCG was conducted once the submarine returned to Pearl Harbor following a total time of deployment of 53 days.

Pre-deployment and Post-deployment Measures

Cooper Test

Aerobic capacity was measured using the Cooper Test (Cooper 1968). All subjects performed the test on the same outdoor track between 10:00 and 11:00 AM. Subjects ran around the track for 12 minutes attempting to reach the farthest distance possible. The distance that each subject achieved was measured with a rolling wheel tape measure (Road Runner™, Model RR-318, Keson®, U.S.A.). Distance was recorded in meters. Subjects wore a Polar Heart Rate Monitor NV™, which recorded heart rate during the run and at least 3-5 min after the run (recovery time). The heart rate monitor was set to record the average heart rate (HR) over each 5-second interval during the test. Heart rate data was downloaded to a Pentium II IBM ThinkPad™ (Operating System: Microsoft Windows 95™) using the Polar Advantage Interface™ and Polar Precision Performance Software™ version 2.02.004. Both SEAL groups performed two pre-deployment runs each separated by one week. The first pre-deployment test enabled the SEALs to gain practice in pacing themselves to run maximally for 12 min. It was assumed that any practice

effects from this first test would not be lost over the study period but would be carried through to the post-deployment test. Due to a busy pre-deployment work schedule the SCG only performed one pre-deployment run on the day before deployment. All subjects performed one run after their deployment period. For the SEAL groups, data from the second pre-deployment test was used in all comparisons with the post-deployment data. The dependent variables recorded from each SEAL's Cooper Test included the distance ran (D), mean exercise heart rate (HR_{mean}), D/HR_{mean}, maximum exercise heart rate (HR_{max}), the slope of the initial heart rate recovery curve ($HR_{recslope}$) and heart rate recovery time ($HR_{rectime}$). $HR_{recslope}$ was derived from linear regression analysis of the first 30 s of HR recovery data. $HR_{rectime}$ was calculated as the time for the HR to drop to 70% of final exercise HR. Only one subject failed to perform a second pre-deployment Cooper test. Data from this subject was still included in the pre versus post-deployment analysis. Three subjects in the NDST group were not included in post-deployment heart rate measures because their data were lost due to battery failure.

Physical Test Battery:
The physical test battery was designed by the Naval Medical Research Institute, in an effort to measure SOF mission-related performance (Thomas *et al*., 1994; Hyde *et al*, 1997). The battery consists of 1) Target Shooting 2) Hand Strength and Endurance 3) Manual Dexterity 4) Step Test 5) Pull-ups. These tests were performed in the order listed. All subjects, except SCG, completed at least two pre-deployment batteries each separated by one week. All subjects completed the battery after each group's respective deployment period.

The target shooting range consisted of 8 targets evenly spaced over a 180° arc subtended 50 feet from the center of the shooter. Targets consisted of three-inch reflectors that were presented at predetermined random intervals (2-4 seconds) and remained in the field of view for predetermined random lengths of time (2-4 seconds). A total of 48 targets were presented for each sequence. A total of 10 sequences were predetermined. No subject practiced or was tested on a previously completed sequence. Subjects used a modified M-16 designed to fire a laser signal and produce recoil with each trigger pull. Subjects wore double hearing protection to limit target detection to visual acquisition. During the pre-deployment period the SEALs were allowed to practice the shooting task during their free time. During each supervised practice trial the number of shots and the number of hits were recorded. For each SEAL the practice trial with the greatest number of hits was used as the pre-deployment score. Only one target sequence was used to determine the post-deployment score.

Left and right hand grip strength and endurance were measured using a proprietary hand dynamometer connected to a laptop computer. The laptop computer displayed real-time feedback of the force exerted on the grip dynamometer. Hand dominance was recorded. Subjects were instructed to squeeze the dynamometer as hard as possible; peak pressure was recorded for maximum grip strength. Immediately upon reaching maximum grip strength subjects were instructed to reduce their grip force to approximately 50% of their maximum grip strength. Using visual feedback of the grip force on the computer screen they were then required to maintain their grip force between 45% and 55% of their maximum grip strength for as long as possible. The computer determined grip endurance by calculating the total amount of time spent above 45% of maximum grip strength. Maximum grip strength for statistical analysis was determined by taking the best value achieved for left and right hand for pre-deployment. Grip endurance for statistical analysis was determined by using the endurance time recorded for the best maximum grip strength for both right and left for pre-deployment.

Manual dexterity was tested using the disassembly and reassembly of an M-16 (Model 727, carbine, and 5.56 mm) rifle. Subjects were instructed on the task and allowed to practice as much as they wished prior to deployment. Practice was not allowed over the deployment. One practice was allowed at post-deployment testing. The average of the total time from start of disassembly to completion of reassembly of the rifle for each individual's last two pre-deployment trials was used for statistical analysis.

Anaerobic performance was tested using a modified Harvard Step Test (two steps, each ten inches in height, for a total of twenty inches vertical rise) with the addition of a 40-lb. weight vest worn during testing. Subjects ascended and descended the stairs as quickly as possible for 60 seconds. Each cycle up and down the stairs triggered a laser counting beam. The number of cycles attained over 60 seconds for the last pre-deployment trial was used for statistical analysis.

Three to five minutes after completion of the step test, each subject performed a maximum number of pull-ups as a measure of upper body strength. The number of pull-ups performed for the last pre-deployment test was used for statistical analysis.

<u>Cognitive Test Battery</u>
This cognitive test battery was designed by the Naval Medical Research Institute, in an effort to measure the basic elements of cognitive function thought to be important in SOF mission-related performance (Thomas and Schrot, 1995; Thomas *et al*., 1995). The cognitive test battery is performed with the aid of a computer and consists of the following tests: 1) Matching-to-sample 2) Complex reaction time 3) Visual vigilance 4) Serial addition-subtraction 5) Logical reasoning 6) Repeated acquisition, in that order. Details of each of these cognitive measures are provided in Thomas and Schrot (1995). The total time required to perform all tests was approximately 20 minutes. We attempted to get each subject to perform approximately six practice sessions during the two weeks prior to deployment. Multiple subjects were tested simultaneously using 14 separate computer stations. Performance on each test is determined by measuring reaction time and accuracy of responses. For all of the cognitive tests, the mean score of the final two practice sessions pre-deployment was compared to the post-deployment score. One submariner was removed from analyses because he completed only one practice session pre-deployment. Subjects were removed from analyses if their response times for tasks that required complex cognitive processing were equivalent to a simple reaction time response and the number of correct responses approached random guessing. No more than two subjects' responses were eliminated from any one cognitive test. Post testing on the DST was conducted on board the submarine the day before disembarking in Korea.

Variables studied throughout study period

<u>Activity Levels</u>
Activity levels were monitored with self-report logs and heart rate monitors. Subjects recorded daily activity on computerized bubble scoring logs (see Appendix A). These logs were filled out for six days prior to deployment, three days at the beginning of deployment and for three days at the end of deployment. Subjects recorded time spent sleeping, working, exercising, eating and doing other activities in half-hour increments. Total time spent for each category, number of sleep periods and the longest single sleep period was calculated for each subject.

The SEALs wore the Polar Heart rate watches for approximately 4 days pre-deployment and for 8 to 11 days throughout the 33-day deployment period. Scheduling conflicts prevented pre-

deployment heart rate monitoring of the SCG. While underway each submariner wore the heart watch for approximately 18 days (range = 9 to 24 days) spread evenly across the submariners 53-day deployment period. The subjects were instructed to wear the heart watches during their waking hours. An attempt was also made to record heart rates during SEAL operations; however, after several watch breakages/losses this was abandoned to prevent further loss of equipment. Average heart rate over each minute was stored in the Polar heart watch memory and then down loaded to a laptop computer at the end of each week. These heart rate data were analyzed offline to determine the duration and intensity of exercise performed by each subject. Exercise was defined by any period of activity that resulted in the average heart rate attaining 100 beats/min or greater for 15 continuous minutes or longer. To account for individual variation in the amount of recorded heart rate data, the amount of exercise performed by each subject was normalized by dividing total exercise duration by the total amount of time over which heart rate data was recorded. Daily exercise intensity for each individual was determined by performing a 15-point unweighted moving average on the minute average heart rate data and then calculating the average heart rate for the exercise periods based upon the moving average data (see example shown in Figure 1).

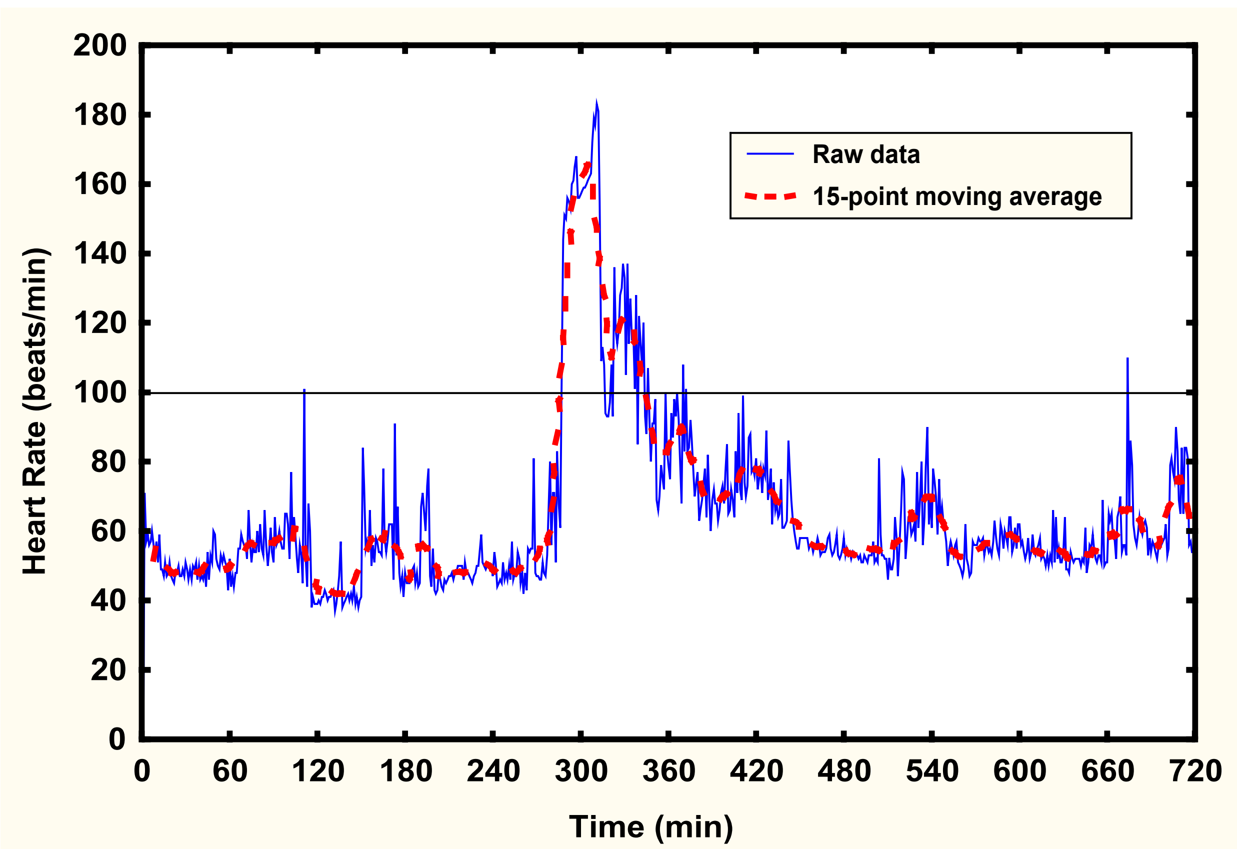

Figure 1. An example of a 12-hour heart rate profile collected from one of the DST during the submarine deployment. The dashed line indicates the smoothed heart rate data following an unweighted 15-point moving average. Time periods where the 15-point moving average attained 100 beats/min or greater were considered periods of exercise. For this individual the duration and mean intensity of exercise during this 12-hour period was 59 minutes and 131 beats/min, respectively.

Mood States
Mood throughout the study was measured with the Profile of Mood States (POMS) questionnaire shown in Appendix C. Subjects scored their response to 13 questions using a visual analogue scale. Subjects were administered the test once per week over the entire study period.

Physical Health Symptoms
During the study all groups completed weekly health-symptoms questionnaires (see Appendix D). This questionnaire was developed by WRAIR for studying American troops deployed in Bosnia. Symptoms were not broken down by severity for analysis.

Sleep-Wake Cycle
Techniques used to document sleep habits included a pre-deployment sleep questionnaire (see Appendix B), the self-report activity logs (Appendix A) and actigraph monitoring. The pre-deployment sleep questionnaire was constructed by NSMRL using elements from sleep surveys previously reported in the scientific literature (Buysse *et al.,* 1989; Kelly *et al.,* 1996). The self-report activity log was designed by NSMRL specifically for the current study. Details of the administration of the self-reported activity logs are provided above in the section on activity levels. Actigraphs are wrist-worn, noninvasive, matchbox-sized devices that record the frequency of movement in three planes of motion. Subjects were instructed to wear the actigraphs continuously, including during sleep, but excluding water exposure. Actigraphs were downloaded approximately every 10 days and were immediately reissued. The longest period of sleep taken during a 24-hr period, total sleep amount in a 24-hour cycle, the number of awakenings and the total wake time was calculated for each subject. Data were collected, stored and analyzed by Walter Reed Army Institute of Research (WRAIR) Department of Operational Stress Research. Their full report is provided in Appendix E.

Caloric Intake
Caloric intake data was gathered from daily self-report dietary logs and weight was measured pre-deployment and post-deployment. Self-report dietary logs were recorded during six days prior to deployment, three days during the first half of deployment and three days during the last half of deployment. Subjects were instructed to record their entire intake except for water. They were given examples of portion sizes to assist in recording their intake. All subjects while onboard the submarine ate meals provided by the submarine mess. Data from the logs were entered into Nutritionist Five™ software, First DataBank, San Bruno, CA, and analyzed for total calories, protein, carbohydrates and fat.

Ambient berthing noise
Ambient noise in DST's and SCG's berthing areas was measured using a Quest™ sound level meter, Oconomowoc, WI. Sound pressure level sampling was done 5 feet from the deck in the center of the berthing space in 48-hour intervals with two measurements 12 hours apart during deployment. Decibels were recorded using an A-weighting and a linear scale. No sound measurements were performed for the NDST.

Submarine atmosphere
Submarine atmosphere was recorded every hour during deployment from the Central Atmosphere Monitoring System (CAMS). Measurements were taken in three areas of the submarine: submariner berthing, Seal Team berthing and the Fan Room. Average partial pressures of oxygen, carbon dioxide, and carbon monoxide were calculated for each day for each location based on the submarine barometric pressure. When the CAMS was non-operational

oxygen and carbon dioxide levels were measured with a portable O_2/CO_2 gas analyzer. Gas measurements were not taken when the submarine ventilated with the outside or when the hatches were open while in port.

Data Analyses

For each individual differences in performance between pre and post-deployment tests were calculated as a percent change from their pre-deployment test. These percent changes were then used to calculate the mean percentage change and ± 95% confidence limits for each Group. Planned comparisons between groups were conducted using independent *t*-tests, while paired *t*-tests were used to compare pre-deployment and post-deployment changes in the dependent variables. Test-retest performance on the Cooper test was assessed using a paired *t*-test and the Pearson Product moment correlation using data from 18 subjects. Sleep, exercise, dietary, and mood data were analyzed using repeated measures analysis of variance. Pre-deployment frequency of reported subjective ailments were compared to deployment frequency using Chi-square. Statistical significance was set for all tests at $p \leq 0.05$.

RESULTS

A total of 31 subjects participated, 10 members in the deployed Seal Team (DST), 9 members in the non-deployed Seal team (NDST), and 12 members in the submariner control group (SCG). The average ages (± SD) of the DST, NDST and SCG were 29 (± 4), 30 (± 6), 28 (± 8) years, respectively. Average active duty time in the Navy for DST, NDST and SCG were 8 (± 2) years, 8 (± 2) years, and 8 (± 4) years, respectively. Prior to this deployment, the DST and NDST were transported on a submarine an average of 10 (± 4) and 5 (± 3) times in their careers, respectively. For each transport, the DST and NDST spent on average 16 (± 10) and 18 (± 20) days on submarine deployment, respectively. The SCG had an average 5 (± 4) years of submarine service with 13 (± 14) transports for an average of 19 (± 20) days spent on each deployment.

Cooper Test

We found a significant practice effect with a 2% mean increase in distance achieved between the first and second trial pre-deployment ($p<0.05$) with no significant change in any of the HR variables. The test-retest correlation coefficient for the distance ran was r=0.79 ($p<0.001$). Individual changes in running performance between the second pre-deployment Cooper test and the post-deployment Cooper test are shown in figure 2. In the NDST there were approximately an equal number of subjects who increased their performance as decreased their performance post-deployment. In contrast all but 2 individuals ran a shorter distance post-deployment than pre-deployment in the DST. All but two members of the SCG showed increased their distance run post-deployment with one individual increasing his distance by almost 1 km. This latter submariner also increased his HR_{max} by 12 beats/min and his HR_{mean} by 4 beats/min during the post-deployment test. Interestingly, the two individuals in the SCG that showed a decrease in distance run post-deployment were the fastest runners in the SCG.

A typical heart rate profile over the 12-min run and during recovery is shown in figure 3. Maximal heart rate was usually attained during the final minute of exercise and reached over 90% of the theoretical age predicted maximum heart rate (i.e. predicted maximum HR = 220 - age) for all subjects during the pre and post-deployment tests. Furthermore, for the SEALs the group average HR_{mean} maintained over the 12-min run was 90% of the predicted maximum heart rate on each of the three Cooper tests. For the SGC the average HR_{mean} was 92% of the predicted

maximum HR during both the pre and post-deployment tests. Table 1 summarizes the comparison between the second pre-deployment test and the post-deployment test for the measured heart rate variables for each group. For the NDST, none of the variables showed significant changes between pre and post-deployment testing. However, the likelihood of showing significant differences in the pre versus post-deployment HR variables for the NDST was reduced due to the small n. The only variable to show a significant difference between the

Table 1
Summary of results comparing heart rate measures on the Cooper test pre[1] and post-deployment. Data are means ± SD.

	Pre-deployment	Post-deployment	n	% Change	-95% Confidence limit	+95% Confidence limit
HR_{mean} (beats min^{-1})						
Submariners	175 ± 10.1	175 ± 9.3	12	+0.1%	-3.2%	+3.4%
DST	174 ± 6.1	175 ± 9.6	10	+0.6%	-2.0%	+3.2%
NDST	164 ± 5.6	166 ± 7.8	6	+1.5%	-0.6%	+3.6%
D/ HR_{mean} (m/beat min^{-1})						
Submariners	13.1 ± 1.57	14.4 ± 1.75	12	+10.1%*	+0.7%	+19.4%
DST	16.3 ± 1.19	15.2 ± 1.39	10	-7.3%**	-10.9%	-3.8%
NDST	16.5 ± 1.35	17.0 ± 1.28	6	+3.2%	-2.9%	+9.3%
HR_{max} (beats min^{-1})						
Submariners	189 ± 10.4	192 ± 9.6	12	+2.0%	-1.3%	+5.3%
DST	185 ± 5.7	185 ± 10.5	10	+0.3%	-2.3%	+3.0%
NDST	176 ± 7.2	179 ± 7.6	6	+1.3%	-1.9%	+4.4%
$HR_{rectime}$ (s)						
Submariners	No data	No data		No data	No data	No data
DST	92 ± 21	136 ± 64	10	+46.8%*	+7.8%	+85.9%
NDST	110 ± 31	140 ± 48	5	+31.5%	-30.2%	+93.1%
$HR_{recslope}$ (beats min^{-2})						
Submariners	No data	No data		No data	No data	No data
DST	-0.748 ± 0.226	-0.605 ± 0.192	10	-17.1%*	-31.3%	+3.0%
NDST	-0.566 ± 0.179	-0.497 ± 0.157	5	-6.9%	-42.7%	+28.8%

Notes:
[1] Data are from the second pre-deployment test for the DST and NDST.
Significant differences between pre and post deployment tests illustrated by * = (p<0.05), ** = (p<0.01)
HR_{mean} = Mean exercise heart rate.
HR_{max} = Maximum exercise heart rate.
$HR_{rectime}$ = Time taken for the heart rate to drop by 30% from that recorded during the final 5 s of exercise.
$HR_{recslope}$ = Slope of the heart rate response during the first 30 s of recovery.
n = number of subjects used in the dependent *t*-test analysis.
DST = Deployed SEAL team
NDST = Non deployed SEAL team

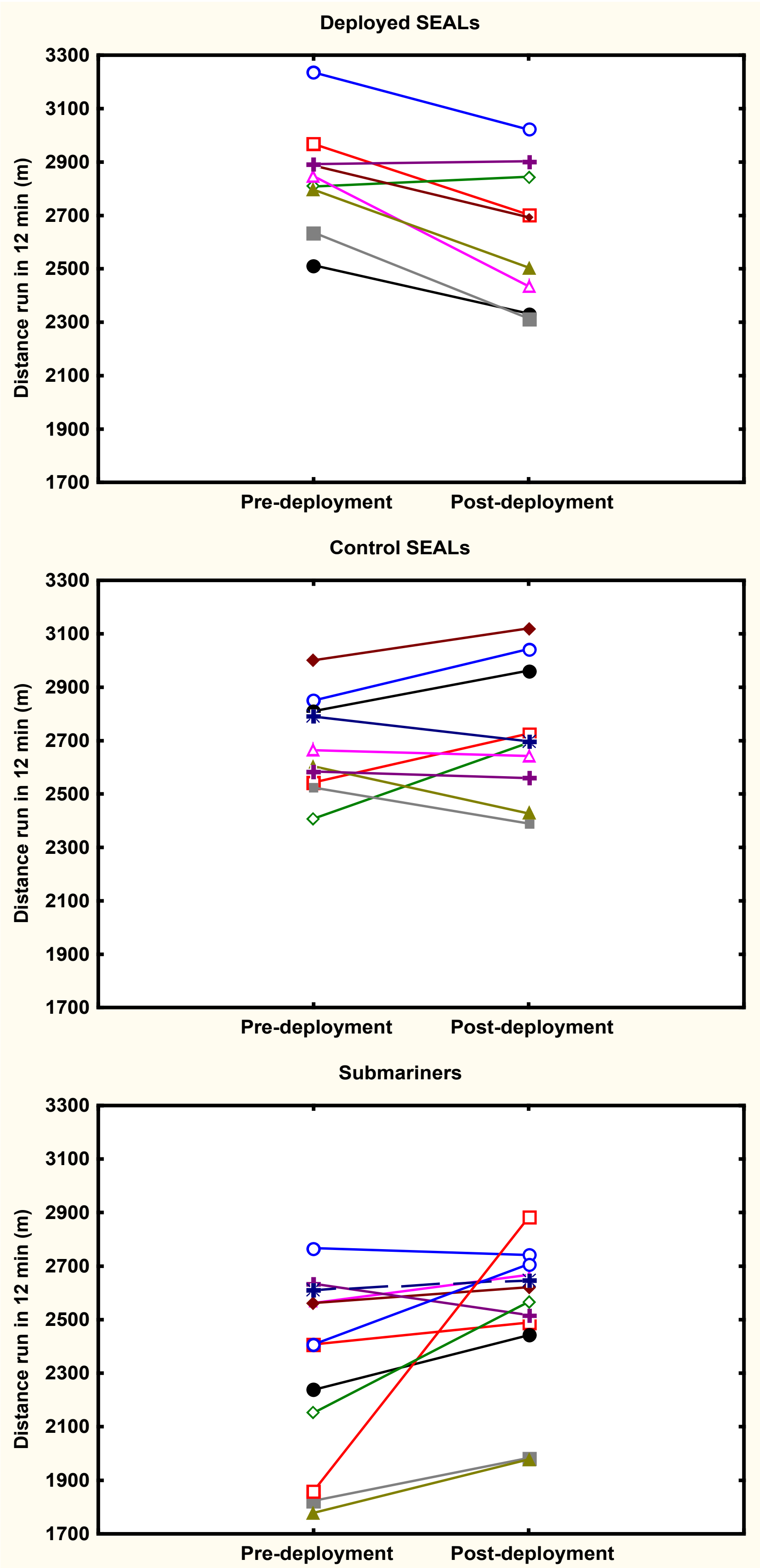

Figure 2. Case profiles showing changes in Cooper test performance between the second pre-deployment test and the post-deployment test for each group.

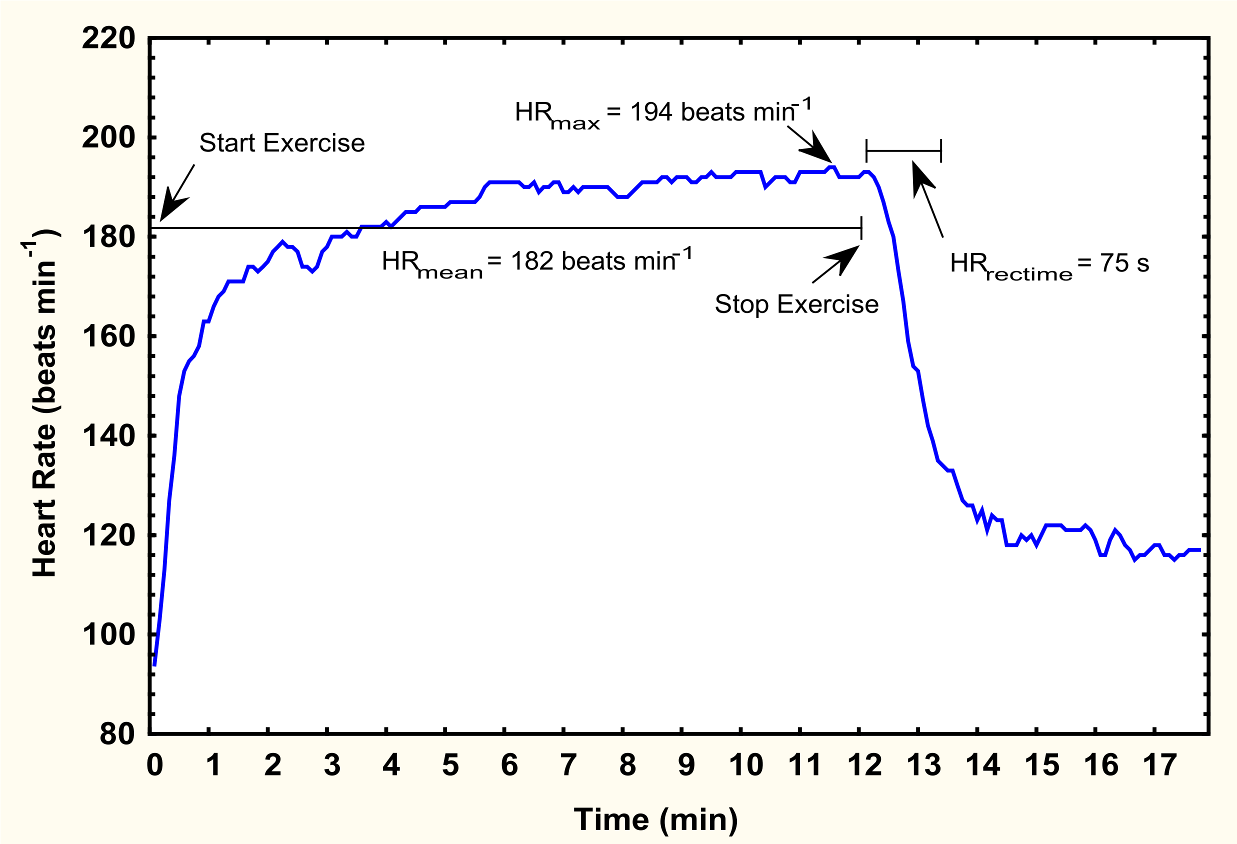

Figure 3. A typical heart rate profile recorded during the post-deployment Cooper test. The theoretical age predicted maximal heart rate (i.e. predicted maximal HR = 220 - age) for this subject was 191 beats/min.

non-deployed and deployed SEALs was the pre-deployment HR_{mean}, which was 9 beats min^{-1} lower for the NDST (p<0.05).

Group statistics showed no significant difference between the DST and NDST before deployment. However, the DST ran significantly farther than the SCG before deployment (p<0.0004, see Table 2). When running performance was expressed as a percentage change in the distance run between the pre and post-deployment tests there was a significant difference between the SEAL groups (p<0.01). The NDST showed a non-significant 2% (SD ± 6.2%) increase in running distance whereas the DST showed a 7% (SD ± 5.1%) decrement in the distance ran following deployment (p<0.01). The decrement in performance of the DST was not associated with any changes in HR_{mean} or HR_{max}. $HR_{rectime}$ was between 8% and 86% longer (± 95% confidence limits) following the deployment (p<0.05). In addition, $HR_{recslope}$ decreased by 17% (p<0.05) and the D/HR_{mean} ratio decreased by between 4% and 11% (± 95% confidence limits, p<0.01) for the DST following deployment (see Table 1). The SCG showed between a 0% and 20% (± 95% confidence limits) significant increase in D/HR_{mean} ratio post-deployment compared to pre-deployment (p<0.03). Although the DST ran on average 5% further than the SCG after deployment, this difference was not significant (p<0.28).

Shooting

The average number of practice trials (± SD) completed by the SEALs pre-deployment was 4.3 ± 1.19 and was similar for both SEAL teams. Due to scheduling conflicts only one shooting sequence was completed pre-deployment by the SCG. When the second and third pre-deployment trials were compared there was no difference in the number of hits scored (p=0.411), however, the test-retest correlation was non-significant (r= 0.015, n=18, p=0.953). Despite poor pre-deployment test-retest reliability shooting performance pre-deployment did show a weak correlation with post-deployment performance (r=0.494, n=31, p<0.01). This significant relationship was largely a result of the SEALs performance since the SCG showed no significant relationship between pre and post-deployment shooting scores (r=-0.077, n=12, p=0.812). The DST scored significantly more hits than the NDST prior to deployment (29.5 vs. 22.1, respectively, p<0.01). There was no effect of deployment on the mean number of hits for any group (see Table 2).

Hand-Grip Strength

We found no significant practice effect for this test. The test-retest correlations were r=0.572 (right hand, p<0.05) and r=0.565 (left hand, p<0.05). We found the right-hand performance correlated with left-hand performance (r=0.653, p<0.05). There was no statistical difference among the three groups before deployment. Maximum grip strength pre-deployment was statistically unchanged compared to post-deployment for all three groups, with the exception of an increase in the left hand of the SCG (p<0.006) (see Table 2).

Hand-Grip Endurance

We found no significant practice effect for this test. The test-retest correlations were r=0.510 (right hand, p<0.05) and r=0.520 (left hand, p<0.05). We found the right-hand performance correlated with left-hand performance (r=0.700, p<0.05). There was no statistical difference among the three groups before deployment. Hand-grip endurance pre-deployment was statistically unchanged compared to post-deployment for all three groups, with the exception of a decrease in the left hand of the SCG (p<0.042) (see Table 2).

Manual Dexterity (Gun Assembly)

We found a significant practice effect for this test with an 11% mean decrease in time to finish between the first and second trial pre-deployment (p<0.02). The test-retest correlation was r=0.620 (p<0.05). There was no was no statistical difference among the three groups before deployment. Manual dexterity pre-deployment was statistically unchanged compared to post-deployment for DST and NDST. There was a significant post-deployment decrement for the SCG (p<0.015) (see Table 2).

Table 2

Summary statistics for the performance of each subject group before and after deployment on the different tests in the Physical Test battery. Significant differences between pre and post-deployment performance are indicated by the * symbol.

Test	**Pre-deployment Mean (SD)**	**Post-deployment Mean (SD)**	**% Change**	**-95% Confidence limit**	**+95% Confidence limit**
Cooper's Test	Distance in meters				
Submariners	2317 (344)	2520 (279)	+10.1%* $p<0.002$	+0.3%	+20.0%
DST	2839 (192)	2646 (242)	-6.8%* $p<0.03$	-10.5%	-3.2%
NDST	2667 (187)	2730 (262)	+2.4%	-2.4%	+7.1%
Shooting	Number of hits				
Submariners	18.5 (4.8)	20.4 (3.6)	+18.2%	-6.3%	+42.7%
DST	29.5 (4.6)	26.4 (5.0)	-9.4%	-22.3%	+3.6%
NDST	22.1 (6.7)	22.2 (8.1)	+5.4%	-21.8%	+32.7%
Right Hand Grip Strength	Pounds				
Submariners	128.2 (18.4)	138.8 (21.6)	+9.4%	-0.9%	+19.6%
DST	127.7 (12.0)	127.1 (15.3)	-0.3%	-6.4%	+5.7%
NDST	129.0 (19.3)	123.9 (15.6)	-2.9%	-12.6%	+6.8%
Left Hand Grip Strength	Pounds				
Submariners	122.6 (22.9)	132.8 (24.4)	+8.7%* $p<0.006$	+3.3%	+14.1%
DST	129.7 (12.0)	124.1 (16.9)	-4.3%	-11.0%	+2.4%
NDST	118.8 (15.9)	121.6 (20.8)	+2.9%	-8.4%	+14.1%
Endurance Right Hand Grip	Seconds				
Submariners	72.4 (22.7)	70.8 (19.1)	+7.9%	-25.6%	+41.4%
DST	66.9 (21.3)	61.8 (19.3)	-1.9%	-28.4%	+24.6%
NDST	72.8 (22.4)	69.7 (21.7)	-2.5%	-19.6%	+14.6%
Endurance Left Hand Grip	Seconds				
Submariners	67.8 (18.7)	54.8 (14.1)	-15.7%* $p<0.042$	-31.9%	+0.5%
DST	63.3 (19.0)	65.2 (21.7)	+10.3%	-25.3%	+45.8%
NDST	75.9 (21.1)	72.7 (15.7)	-0.7%	-18.1%	+16.8%
Manual Dexterity[1]	Seconds				
Submariners	109.2 (30.6)	152.6 (69.9)	+38.1%* $p<0.015$	+9.4%	+66.9%
DST	89.8 (16.4)	104.4 (28.4)	+17.4%	-3.8%	+38.7%
NDST	114.5 (41.1)	105.7 (31.9)	-3.9%	-22.7%	+14.9%
Step Test	Steps/minute				
Submariners	55.6 (6.5)	60.7 (7.4)	+9.2%* $p<0.005$	+3.0%	+15.9%
DST	71.5 (7.3)	64.9 (8.4)	-9.2%* $p<0.006$	-14.9%	-3.5%
NDST	66.8 (4.7)	67.0 (6.5)	+0.3%	-5.8%	+6.7%
Pull-ups	Counts				
Submariners	8.1 (4.6)	8.2 (4.3)	+7.5%	-12.1%	+27.1%
DST	17.3 (3.4)	17.0 (4.6)	-0.3%	-20.4%	+19.9%
NDST	17.9 (5.2)	19.0 (4.4)	+8.4%	-1.9%	+18.7%

[1]Note: An increase in time or positive change on this test is indicative of poorer performance.

Step Test

We found a significant practice effect for this test with a 12% mean increase in the number of steps between the first and second trial prior to deployment (p<0.0001). The test-retest correlation was r=0.835 (p<0.05). Individual changes in Step test performance between the second pre-deployment test and the post-deployment test are shown for each group in figure 4. In the NDST there were four individuals who increased performance, three who decreased their performance, and two who showed no change following the deployment period. In the DST all but one individual showed a decrease in their performance after the deployment. In contrast all but 2 submariners improved their performance on the post-deployment test. Group statistics showed no significant difference between the DST and NDST before deployment. However, the DST and NDST combined achieved significantly more steps than the SCG before deployment (69 steps/min vs. 55 steps/min, respectively, p<0.0001). Mean number of steps/min pre-deployment was statistically unchanged compared to post-deployment for the NDST. For the DST the mean number of steps/min post-deployment decreased compared to pre-deployment (p<0.006) but increased for the SCG (p<0.005). After deployment there was no longer a statistically significant difference in performance between DST and SCG (see Table 2).

Pull-ups

We found no significant practice effect for this test. The test-retest correlation was r=0.96 (p<0.05). There was no statistical difference between the DST and NDST before deployment. However, the DST and NDST combined achieved more pull-ups than the SCG before deployment (18 vs. 8, respectively, p<0.00001), this difference was unchanged after deployment. The number of pull-ups post-deployment was statistically unchanged compared to pre-deployment for all three groups (see Table 2).

Cognitive Tests

We found no significant changes in any of the three groups between pre-deployment and post-deployment measures of time-to-completion or number of errors for matching-to-sample, complex reaction time, visual vigilance, logical reasoning, or repeated acquisition. We did find a significant slowing in post-deployment mean response time for serial addition-subtraction compared to pre-deployment. This slowing was seen for all three groups, SCG (2232 vs. 2040 msec, respectively, p<0.004), DST (2049 vs. 1807 msec, respectively, p<0.04) and NDST (2170 vs. 1897 msec, respectively, p<0.06). There was no change in errors for serial addition-subtraction for any of the three groups over the same testing period.

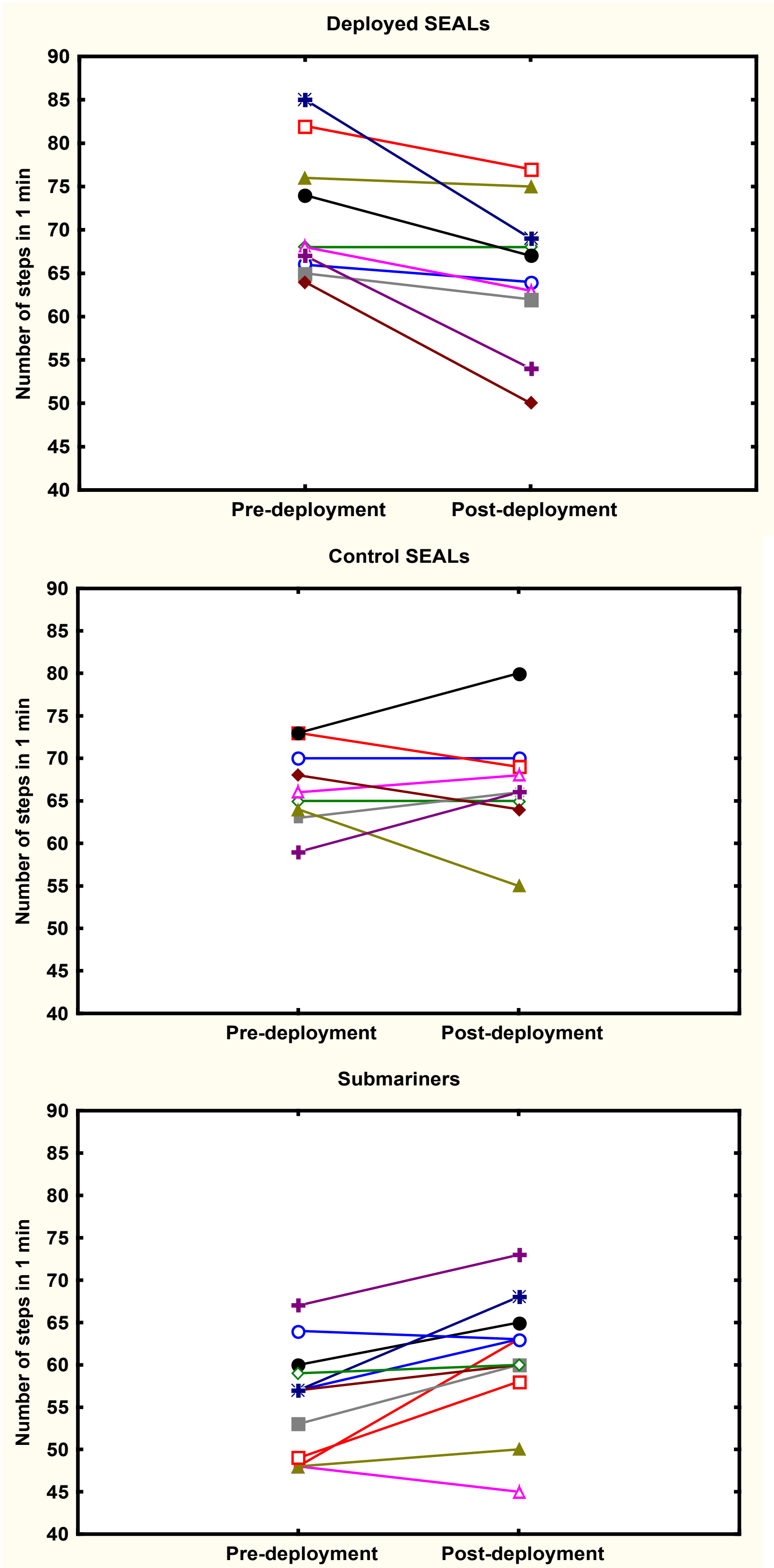

Figure 4. Case profiles showing changes in the Step test performance between the second pre-deployment test and the post-deployment test for each group.

Activity Levels

For the NDST, there were no changes in time spent eating, working or recreating over the study period. Over the early deployment period the DST spent significantly more time eating and recreating and less time working than the SCG (p<0.001). For this same time period the DST had 66% more free time (recreational time) than the NDST (p<0.001). During the late deployment period there was no difference in hours spent eating and working between DST, CSG, and NDST. Over the study period no group significantly changed their amount of time spent exercising. However the DST spent significantly less time exercising than the NDST over the entire study period, 0.7 vs. 2.5 hours/day, respectively (p<0.01). The SCG spent on average 1.5 hours exercising/day over the study period. There was no statistically significant difference between the DST and the SCG in time spent exercising (p<0.07).

Analysis of the heart rate data showed similar results to that described above for the activity logs. For the NDST the total duration of exercise (see Methods section for definition of exercise duration based upon HR data) was similar across the study period. During the pre-deployment period the NDST spent 9.7% (± 7.8% (SD)) of their total monitored time exercising compared with 9.4% (± 7.6%) during the deployment period (p=0.924). In contrast the DST spent 11.0% (± 13.4%) of their total monitoring time exercising during the pre-deployment period and only 5.2%(± 3.1%) during the deployment period (p=0.275). Based upon the HR data there were no statistically significant differences in the amount of time spent exercising among the three groups during the deployment period or between the NDST and DST during the pre-deployment period. For the NDST and the DST the intensity of exercise tended to be slightly greater during the deployment period (NDST = 126 ± 15 beats/min (mean ± SD); DST 126 ± 6 beats/min) than during the pre-deployment period (NDST = 115 ± 12 beats/min (mean ± SD); DST 113 ± 8 beats/min). Although the intensity of exercise during deployment was significantly greater than that during pre-deployment in the DST (p<0.05), there was no significant difference in exercise intensity between the pre-deployment and deployment periods in the NDST (p=0.330). This lack of significance was largely due to the high variability in exercise intensity among the NDST. During deployment the mean exercise intensity for the SCG was 111 ± 6 beats/min which was significantly lower than that recorded for the NDST (p<0.01) and the DST (p<0.0001).

Mood

There were no significant changes in any of the 13 parameters of mood measurement for the NDST over the study. However for the DST, there were significant increases in feelings of annoyance, frustration, discouragement, depression, irritability, and tiredness (p<0.05). They also had a significant decrease in contentment, energy and activity levels (p<0.05). There were no changes in feelings of comfort, stress, nervousness, or tension. The SCG had no change in any of the above parameters except for an increase energy during early deployment relative to all other periods (p<0.05) and a decrease in activity over the deployment (p<0.003). There were no differences in mood parameters between DST and NDST pre-deployment. However, the DST's mood in every category other than discomfort and nervousness was significantly worse than NDST during and after the deployment period (p<0.05).

Health

There were no changes in any of the 21 health symptoms reported by the SCG during patrol compared to prepatrol. For the NDST there was a decrease in muscle aches and rashes during the

patrol period compared to prepatrol (both, $p<0.04$). During patrol, the DST had increases in the frequency of sinus troubles ($p<0.03$), headaches ($p<0.04$), backaches ($p<0.06$), constipation ($p<0.04$), and cuts/sores ($p<0.03$) compared to prepatrol. Whereas, the DST had lower complaints of muscle aches ($p<0.04$) during patrol compared to prepatrol (see Table 3). For the DST, the frequency of the following symptoms did not change during deployment compared to pre-deployment: flu, head cold, sore throat, difficulty swallowing, allergies, stomach/intestinal upset, skin rash, eye/ear/nose problem, chills/fever, hoarseness, heart problems, weight loss/gain, dizziness or injury.

Table 3
Symptoms with significant cumulative frequency changes

Control SEALs	Prepatrol	Patrol	*p* value
Muscle aches	47%	20%	0.038
Rash	24%	5%	0.037
Deployed SEALs			
Sinus problems	20%	48%	0.032
Headaches	35%	63%	0.038
Backaches	25%	50%	0.058
Constipation	0%	19%	0.038
Cuts/sores	0%	21%	0.0271
Muscle aches	40%	17%	0.039

<u>Sleep</u>
Sleep data from the activity logs for longest sleeping session and total sleep for each group broken down by prepatrol, early patrol (transit time) and late patrol (operations) are tabulated in Table 4. Both the SCG and the NDST had no change in their longest sleep session or total hours slept during a twenty-four hour period over the entire study. However, the DST had a 29% mean increase in their total sleep time from prepatrol to early patrol (7.7 vs. 9.9 hours, respectively, $p<0.03$). Their total sleep time prepatrol was significantly longer than either SCG or NDST ($p<0.05$). During active operations (late patrol), the DST had a decrease in their longest sleep session compared to early patrol and prepatrol (5.2 vs. 6.7 and 6.6 hours, respectively, $p<0.03$). The decrease in longest sleep session was also less than either SCG or NDST for the late patrol period ($p<0.02$).

Walter Reed Army Institute of Research report in Appendix E provides a full description of the sleep patterns derived from the actigraph data. Although data artifact arising from an unknown source while aboard the submarine made analysis of the sleep patterns for the SCG and DST difficult there was sufficient data to make some comparisons between the actigraphs and sleep logs over the entire study. On average, for the longest sleep session, subjects reported 0.7 hours (42 minutes) more sleep on the sleep logs than were recorded on the actigraph, 6.9 vs. 6.2 hours/day, respectively ($p<0.01$). It should be noted that the smallest resolution of the sleep log was 0.5 hours (30 minutes) compared to the resolution of 0.017 hours (1 minute) for the actigraph data.

Table 4
The Amount of Sleep Logged for a 24 hour Period

Control SEALs	**Prepatrol**	**Early Patrol**	**Late Patrol**	**Significance**
Longest Sleep	7.4 (0.6)	6.9 (1.1)	7.3 (0.8)	No difference
Total Sleep	8.1 (0.8)	7.3 (1.1)	8.4 (1.3)	No difference
Deployed SEALs				
Longest Sleep	6.6 (0.9)	6.7 (1.7)	5.2 (1.4)	Early vs Late p=0.026; Pre vs Late p=0.013
Total Sleep	7.7 (1.2)	9.9 (2.4)	8.1 (2.5)	Pre vs Early p=0.021
Submariners				
Longest Sleep	6.8 (2.6)	6.7 (1.7)	7.0 (1.5)	No difference
Total Sleep	7.6 (2.4)	8.7 (2.6)	8.1 (1.6)	No difference

Notes: Values are means (SD)

Caloric Intake

A summary of the dietary analysis performed on each experimental group is shown in Table 5. There were no differences in total daily caloric intake or the amount of protein, carbohydrate or fats consumed between any of the groups pre-deployment or in the amount of protein and carbohydrates eaten during the deployment. During early deployment the SCG and DST consumed a greater amount of fat than the NDST (SCG vs. NDST, $p<0.001$; DST vs. NDST, $p<0.05$). During the late deployment period the NDST had similar total daily caloric intake and protein, carbohydrate and fat consumption as the SCG and DST. However, during this same time period, the DST reported a lower total daily caloric intake than the SCG ($p<0.05$) which was predominantly a result of a lower amount of fat consumed by the DST compared to the SCG ($p<0.05$).

A comparison of the dietary logs within groups revealed that the SCG did not change their total daily caloric intake or the amount of protein, carbohydrate or fats eaten during the entire study period. In contrast, the DST had a significant reduction in their carbohydrate intake during early and late deployment relative to pre-deployment (both $p<0.05$). However, this reduction in carbohydrate consumed during deployment did not result in a significant change in the total daily caloric intake over the study period ($F_{2,74} = 2.8$, $p=0.064$). The NDST reported a significant reduction in their daily caloric intake during the early ($p<0.01$) and late deployment time period ($p<0.05$) compared to pre-deployment. The reduction in caloric intake by the NDST during the deployment phase was a result of a lower consumption of protein and carbohydrates during both early and late deployment compared to pre-deployment (all comparisons $p<0.05$). There were no

significant differences in weight between DST and NDST. Differences in body weight between DST and SCG did not reach statistical significance (84 kg vs 91 kg, respectively, p=0.08).

Ambient Noise

A-weighted noise measurements of the DST's berthing area were significantly higher than the SCG's berthing area over the deployment, 57 vs. 43 dB, respectively (p<0.000001). This difference resulted in a berthing area for the DST that was louder than SCG's berthing area for noise weighted in the human hearing range. Comparison of the berthing areas was not significantly different for noise measured on a linear scale 80 vs. 79 dB, respectively.

Submarine Atmosphere

There was a total of 26 days of atmosphere data collected over the 33 days of SEAL Team deployment. Carbon monoxide levels never exceeded the limit of 15 ppm in any of the three locations over the deployment. The mean carbon monoxide level over the deployment was 1.65 ppm. Daily mean oxygen levels exceeded the upper limit of 160 mmHg for 3 of the 26 days (12%). There was no day in which the mean oxygen level fell below the 130-mmHg limit. The average oxygen level over the deployment was 145 mmHg (see figure 5). Daily mean carbon dioxide levels exceeded the limit of 3.8 mmHg for 9 of the 26 days (35%). The average carbon dioxide level over deployment was 3.5 mmHg (see figure 6).

Table 5
Dietary analysis showing the average daily caloric intake (KCal) and average amount of protein, carbohydrates and fat (in grams) consumed per day during the study period by each experimental group.

		Mean	SD	SEM	Range
Pre-deployment					
Control SEALs	KCAL	2836	1182	203	5551
	PROTEIN	124	58	10	238
	CARB	335	128	22	670
	FAT	94	62	11	301
Deployed SEALs	KCAL	2464	1370	250	6710
	PROTEIN	100	42	8	154
	CARB	285	147	27	628
	FAT	85	57	10	215
Submariners	KCAL	2767	1235	178	5407
	PROTEIN	109	42	6	188
	CARB	352	207	30	1010
	FAT	97	45	7	194
Early Deployment					
Control SEALs	KCAL	2054	522	114	2180
	PROTEIN	100	44	10	181
	CARB	258	86	19	378
	FAT	62	32	7	99
Deployed SEALs	KCAL	2038	636	122	2705
	PROTEIN	107	34	7	128
	CARB	201	103	20	386
	FAT	93	31	6	127
Submariners	KCAL	2423	1019	170	4477
	PROTEIN	107	46	8	211
	CARB	277	154	26	774
	FAT	102	43	7	178
Late Deployment					
Control SEALs	KCAL	2176	626	128	2553
	PROTEIN	89	24	5	86
	CARB	261	99	20	399
	FAT	81	49	10	202
Deployed SEALs	KCAL	1813	613	137	2157
	PROTEIN	106	49	11	168
	CARB	204	79	18	332
	FAT	61	25	6	83
Submariners	KCAL	2458	1092	182	4579
	PROTEIN	105	43	7	166
	CARB	271	134	22	538
	FAT	99	47	8	222

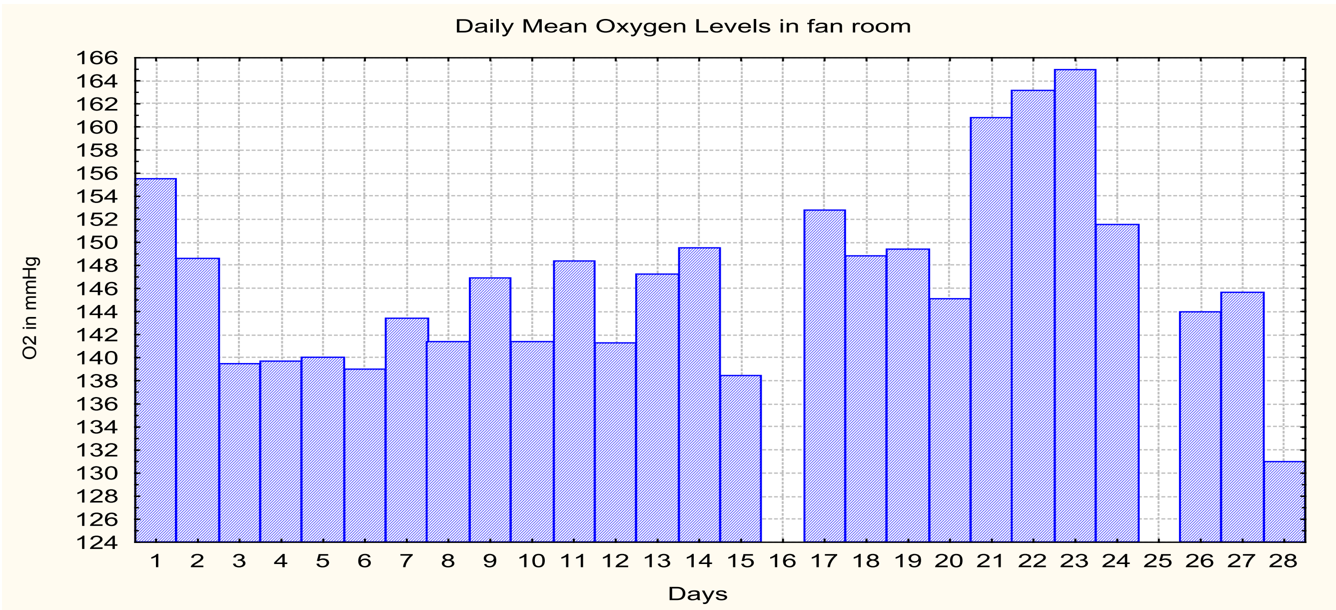

Figure 5. Daily mean oxygen levels in the fan room

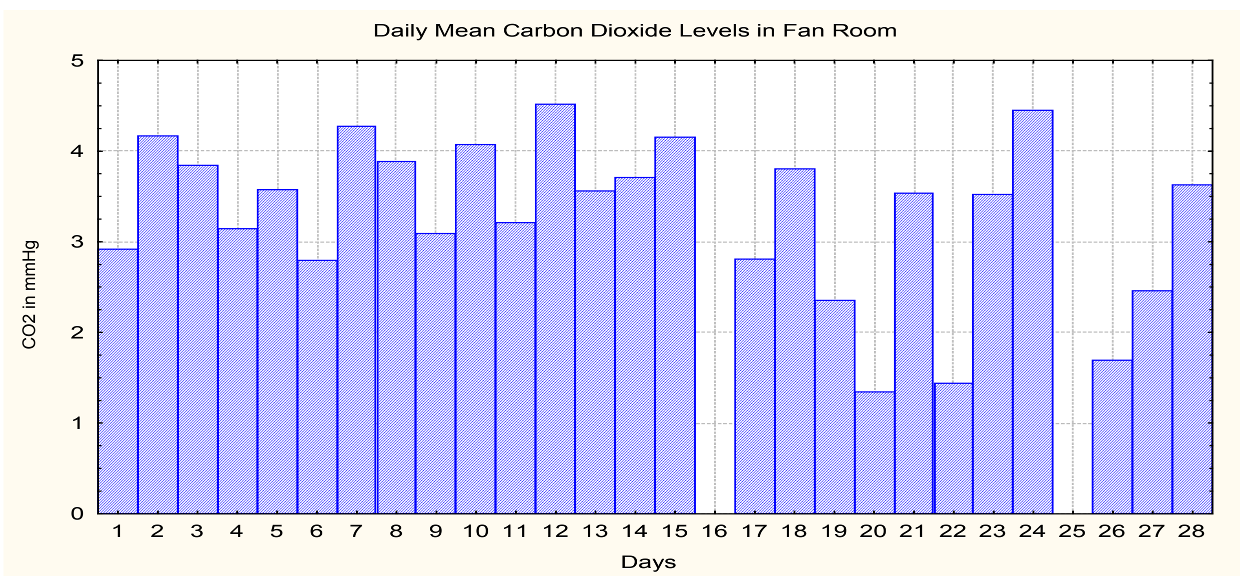

Figure 6. Daily mean carbon dioxide levels in the fan room

DISCUSSION

The results of the current study indicate that SEALs experience a significant decrease in aerobic and anaerobic performance following a 33-day submarine deployment. The decrease in aerobic performance was not associated with changes in exercise heart rate since HR_{mean} and HR_{max} were similar during the pre and post-deployment Cooper tests. However, it is well known that changes in running performance after training or detraining greatly exceed any associated changes in the cardiovascular system involving oxygen consumption or heart rate (Lambert *et al.,* 1998). Consequently, the distance run on the Cooper test will give a better indication of an individual's state of aerobic conditioning than measures of exercise heart rate. Furthermore, from a practical perspective running performance is more directly related to the physical demands of actual mission performance than physiological measures of cardiovascular function.

However, misleading or inappropriate conclusions could occur if running performance is used as the sole criterion for determining the state of aerobic conditioning in individuals whose motivation to perform maximally may differ between testing conditions. Even though the SEALs are known to be highly competitive and motivated individuals (Braun, 1994) the fact that they knew the objectives of the study, could have influenced them to under perform following deployment to magnify deconditioning effects. This strategy is motivated by the fact that large decrements in aerobic performance following the submarine deployment might prompt SEAL commanders to find alternative methods to deploy their troops for future missions. From the deployed SEALs perspective this would mean less time away from home and family, as well as less time within the cramped confinements of the submarine. Our data on mood changes verify the hypothesis that SEALs do not "enjoy" their deployment time. In fact, 9 of the 13 mood parameters indicated increases in negative emotions during the deployment. In contrast, submariners had no change in 11 of 13 mood parameters. Despite this knowledge, the similar pre and post-deployment exercise HR data suggest that the subjects were equally motivated during the pre and post-deployment Cooper tests. Since running speed (and hence distance achieved in a given time) is linearly related to exercise HR (Lambert *et al.,* 1998) one would expect the D/HR_{mean} ratio to be unchanged if motivation factors were the only variable to influence running speed between different testing conditions. However, the deployed SEALs showed a significant decrease in the D/HR_{mean} ratio post-deployment. Since a decrease in D/HR_{mean} indicates that running performance is less efficient, the results suggest either a real deconditioning effect or significant differences in the environmental testing conditions between the pre and post-deployment tests. Since the pre and post-deployment tests were conducted at the same time of day under similar weather conditions, the decrease in running performance is most likely a result of aerobic deconditioning.

Further evidence of aerobic deconditioning in the deployed SEALs is reflected by the changes in the recovery heart rate profiles following the Cooper test. Heart rate recovery is correspondingly faster in those individuals who have a higher aerobic capacity (Cardus and Spencer, 1976; Hagberg *et al.,* 1980; Kirby and Hartung, 1980; Darr *et al.,* 1988). Furthermore, endurance training results in a more rapid rate of recovery in HR following exercise (Hagberg *et al.,* 1980). Consequently, in the present study, slower rates of heart rate recovery following exertion were attributed to a deconditioning effect. We provide two indices of HR recovery that may be useful

to follow changes in the aerobic training status of an individual. The first index, $HR_{rectime}$, provides a quick field-based estimate of aerobic training status that requires few calculations or knowledge about the characteristics of the HR recovery profile. This index includes both the initial fast component and a portion of the subsequent slow component of the exponential decline in HR following exercise (Imai *et al.,* 1994). Because the time constant of the slow component of the HR recovery curve depends on the exercise workload (Imai *et al.,* 1994), $HR_{rectime}$ will be somewhat sensitive to differences in the running speed between tests. Results of the present study indicate that the deployed SEALs had a substantial increase in recovery time following the submarine deployment as measured by the $HR_{rectime}$ index. This finding is tempered somewhat by the fact that the control SEALs also showed an increase in $HR_{rectime}$ all be it a non-significant one.

The second index of HR recovery, $HR_{recslope}$, focuses on the initial fast component of the HR recovery curve which is unaffected by differences in the workload of the preceding exercise (Millahn and Helke, 1968; Nandi and Spodick, 1977; Imai *et al.,* 1994). Past research has shown that there are marked differences in the fast phase of recovery between aerobically trained and untrained individuals (Darr *et al.,* 1988). In the present study, the lack of a significant difference in $HR_{recslope}$ between the DST and NDST post-deployment most likely reflects the large variability of this measure within the groups as well as the small sample size of the groups. However, results from the more powerful within group analysis show a significant 17% decrease in $HR_{recslope}$ of the deployed SEALs following deployment. Nevertheless, the 95% confidence intervals for the change in the $HR_{recslope}$ are large and show a substantial overlap with the 95% confidence intervals for the $HR_{recslope}$ of the NDST

Our results on the one-minute step test suggest that DST's anaerobic condition was also adversely affected by the submarine deployment. Previous studies have demonstrated up to 20% decrements in the anaerobic threshold of non-exercising submariners after a prolonged deployment (Bennett *et al*., 1985). Despite the DST's superior performance in both the step-test and Cooper test performance pre-deployment compared to the SCG, they were found to perform only marginally better (but not statistically significantly better) than the SCG after deployment. An aerobic and anaerobic performance of the DST that is statistically no better than the submariner's performance is of considerable concern, given that, other than teamwork, stamina was listed as the most important attribute to successful completion of SEAL operations (Prusaczyk *et al*., 1995).

One of the main reasons for the statistically similar levels of physical fitness between the SCG and DST post-deployment was the significant improvement in anaerobic and aerobic performance of the SCG. This is in marked contrast to previous studies in which significant decrements in physical fitness have been found in submariners following a deployment (Knight *et al.,* 1981; Bennett *et al*., 1985). In the current study, practice effects will likely account for some of the SCG's improved performance after deployment since this group only performed the physical test battery once prior to deployment. An additional factor that may have contributed to the increase in post-deployment performance is subject selection bias. Of note was the fact that several of the SCG were close to not meeting the US. Navy physical readiness standards and used the study as a means to motivate themselves to improve their fitness. Furthermore, the SCG reported exercising on average more than twice as long as the DST during the study period.

However, the variability in the reported daily exercise time of the DST and SCG groups was such that this difference was not statistically significant.

The precise cause of the deployed SEALs deconditioning is less clear. Unlike submarine personnel, SEALs do not have to perform any watch standing during their transit time to the theater of operations as evidenced by the significant increase in self reported hours spent sleeping, eating, and recreating during early deployment. Thus, during this transit period SEALs have considerably more free time to exercise compared to when they are ported at their home base. This increased time available for physical training may not be utilized due to the limited space and availability of exercise equipment on board. The DST's constellation of increased medical symptoms in headache, backache, constipation and sinuses fit the construct of increased inactivity or time spent in recumbent positions. Furthermore, decreased motivation and disruption from their command physical training regimen might impact a SEAL's adherence to a regular training program while on submarine operations (Vickers *et al*., 1982). Despite these factors, the deployed SEAL's activity logs showed no change in the amount of daily exercise performed between the pre-deployment and deployment study period. However, the DST consistently spent less time exercising than their non-deployed colleagues did.

STUDY LIMITATIONS

A caveat to these data should be made in view of the possibilities that the statistical analyses may contain Type I and Type II errors. A Type I error occurs when the true hypothesis of no difference between two means is erroneously rejected. Due to the large number of variables analyzed in this study it is probable that there are several false positive results. As each comparison was an *a priori* planned comparison, analysis of the data are presented without correction for multiple comparisons. The second type of error (Type II error) occurs when we falsely accept the hypothesis that there is no difference between two means. This can occur when there is an insufficient number of subjects to confidently detect a significant difference between two means. Due to the large variability inherent in field based studies it is desirable to employ large sample sizes to ensure sufficient statistical power to observe significant differences between groups in the variables of interest when they exist. In the present study operational requirements and the small subject population pool limited the number of subjects in each group. For example, for the DST the entire complement of individuals on the mission volunteered as subjects. Consequently, there may be several comparisons where even though large differences were shown there was insufficient statistical power to observe a significant difference at the $p<0.05$ level. In view of this fact the reader should keep in mind the 95% confidence limits shown for the percent change for the different variables between pre and post-deployment when interpreting the statistical findings shown in the results section.

For some of the performance tests the 95% confidence limits for the percent change in performance between the pre and post-deployment test is quite large. The source of this variability in the different groups is wide ranging and can include: natural day-to-day variability, test-retest reliability of the given test, differences in motivation, as well as individual response differences to prolonged confinement aboard the submarine. The results provide an indication of systematic bias resulting from practice effects and relative test-retest reliability for the different

tests in the physical performance battery. While some test showed good test-retest reliability (e.g. pull-ups) others showed poor reliability. In particular the shooting test showed little consistency in relative subject performance for the number of hits on target during repeated testing. In view of the poor relative reliability of the shooting test this test may not be reliable enough to detect a measurable change in performance as a result of the deployment. However, it should be noted that shooting performance was conducted under rested conditions and before completing the running test. It is possible that if the shooting test had been performed immediately following the Cooper test that the effects of the deployment on shooting performance may have been more apparent. Given the fact that the recovery time after aerobic activity is longer following the deployment it is possible that shooting performance immediately after extended physical activity could be impaired to a greater extent following deployment than before deployment.

Some of the poor repeatability in test-retest performance may be due to differences in subject motivation at the difference test times. Although analysis of the SEALs heart rate data during the Cooper tests suggest that individuals were motivated sufficiently enough to approach maximal performance during the running test, this may not have been so for other tests. Anecdotal observations suggest the strong possibility that certain subject's motivation were not constant over the study period.

An additional confounding factor that may have potentially impacted post-deployment performance of the DST is the five-hour time difference between Korea and Hawaii. Although the DST performed the pre and post-deployment tests at the same time of day, their circadian rhythms will likely have not been fully synchronized with Hawaii Time during the post-deployment testing. Experimental studies on the effects of circadian rhythms on performance have shown that factors such as flexibility, muscle strength and short term high power output vary with time of day in a sinusoidal manner and peak in the early evening close to the daily maximum in body temperature (Atkinson and Reilly, 1996). Furthermore prolonged submaximal exercise carried out in hot conditions shows optimal performance in the morning (Atkinson and Reilly, 1996). However, in the present study any jet-lag or circadian asynchrony in the DST will likely have had only a small impact on their post-deployment performance tests for a number of reasons. Firstly, the DST were not tested until at least 24 hours after arriving in Hawaii, thus permitting a certain amount of recovery from the jet-lag before testing. Secondly, the considerable interindividual variation in responses to sleep loss (Meney et al., 1998) as well as individual differences in performance rhythms (Atkinson and Reilly, 1996) will likely have reduced the chances of observing a statistically measurable circadian change in performance between the pre and post-deployment tests. The lack of a significant difference in hand grip strength between the pre and post-deployment tests provides some evidence to suggest that circadian effects if present had minimal impact on the DST post-deployment performance. Nevertheless evidence from the scientific literature suggests that small decreases in anaerobic capacity and running performance could be expected immediately following an eastward flight across six time zones (Wright et al., 1983).

During field based experiments it is not always possible to perform pre and post-deployment tests at the same time of day or at the same time points in the circadian cycle. When this occurs, the effects of circadian variation may significantly compound or alleviate any performance changes resulting from other mission related environmental stresses. Clearly some means of

accounting for circadian variation on the performance of the physical and cognitive test batteries is needed to better isolate the effects of environmental factors on mission related performance. It is therefore recommended that the current physical and cognitive SOF mission related test batteries undergo a carefully controlled study to detect the influence of circadian variation on the various tests. Such a study is needed so that (1) past and future studies may better determine the true effects of other environmental stresses on mission related performance and (2) to determine the utility of each test from the standpoint of repeatability.

As the current study was a non-interventional field study conducted during actual training operations there were many intervening variables that could potentially impact SEAL performance. Attempts were made to monitor those variables that were thought to potentially have the largest effect on SEAL performance. Monitoring techniques were used that attempted to minimize the impact on the SEALs mission while obtaining the necessary data. However, to have minimal impact on the DSTs mission the periods selected for heart rate monitoring may not have been representative of the average activity levels over the deployment period (i.e., monitoring during particularly quiet or busy periods of time). Several attempts were made to monitor activity levels and heart rate during Dry Deck Shelter (DDS) and Seal Delivery Vehicle (SDV) operations, however repeated losses and breakage's of our monitoring equipment necessitated aborting data collection during these operations. Consequently, activity levels of the DST (based on the heart rate data) may have been underestimated during the latter stages of the mission when DDS/SDV operations were conducted.

One unexpected finding was that exercise intensity of the DST derived from the heart rate data was significantly greater during deployment than during the pre-deployment period. This finding possibly reflects the nature of activities preformed during the week prior to deployment when both heart rate and the activity log data were collected. Due to the limited number of days of heart rate monitoring during the pre-deployment period it is possible that the combination of sampling bias and the changes in the SEAL's work schedules (required to prepare for the mission) resulted in estimates of exercise intensity that were atypical of their normal working week at their home command.

The large differences in reported daily exercise time between the control SEALs and deployed SEALs during the week before deployment may reflect the lack of free time available for the deployed SEALs to do additional physical exercise due to the demands of preparing for the mission. Indeed the DST reported working longer hours than the NDST during the pre-deployment period. However, the duration of exercise determined from the pre-deployment heart rate data did not confirm differences in exercise time between the two SEAL groups. This discrepancy could be due to a number of factors. Firstly, the heart rate data does not distinguish between heavy physical work performed during their normal daily routine and formal scheduled exercise. In contrast the activity logs separate out the time spent working and the time spent exercising. If the DST spent a good portion of their working hours doing heavy manual work (i.e., packing equipment for the mission) it will be counted as exercise time if their heart rate was maintained above 100 beats/min for 15 min or longer. Therefore even though the DST spent less time formally exercising during the pre-deployment period than the NDST, the increase in heavy physical activity during the DST working hours may have offset the reduction in formal exercise.

One of the limitations of the activity logs is that they do not show if there were any differences in the intensity or type of exercise performed while on land or aboard the submarine. It is possible that the DST switched from a predominantly aerobic training program pre-deployment to a largely calisthenic and strength training program during the mission and/or that the intensity of their aerobic workouts while aboard the submarine were significantly reduced. Even if the duration and frequency of exercise is maintained constant, reductions in training intensity can lead to a significant loss in aerobic power (Hickson *et al.,* 1985). However, evidence from the heart rate data collected during deployment shows that the intensity of exercise was similar in the DST and NDST. According to this finding it would seem that the deconditioning of the DST does not appear to be a result of a reduction in the intensity of exercise while aboard the submarine.

A more likely explanation for the decrease in running performance of the DST following deployment is a reduction in running specific training aboard the submarine. Although there was one treadmill aboard the submarine demand for its use may have necessitated that the SEALs switch to the other forms of exercise. The other types of exercise equipment available aboard the submarine included two rowing machines, one stair climber, two exercise bikes and a set of free weights. Due to the specificity of training, even if other non running aerobic activities (e.g. bicycling) are substituted for running training current evidence suggests that there is limited cross training benefits to be gained (Pierce *et al*., 1990; Tanaka, 1994). Consequently, a prolonged layoff from running specific training could lead to reduced running performance despite substituting running training with other forms of aerobic exercise.

A further study limitation was the fact that post-deployment testing on most of the DST was conducted 9 days after they left the submarine (two SEALs remained on the submarine for a further 4 days before flying home). During the first 7 days after leaving the submarine the DST were in Korea waiting for commercial air transportation to Pearl Harbor, HI. As no monitoring of activity was conducted during this period little is known of their activity levels during this time. Given the free time and opportunity it is likely that the SEALs continued some sort of aerobic training. If activities such as running were engaged in during this free time it is possible that some of the decrements in aerobic performance resulting from the submarine deployment may have been offset. However, the extent of any activity during this time period and its potential effects on post-deployment test performance is unknown.

One final note that should be considered when interpreting the results of the current study is that this research was performed on a single submarine platform using SEALs from one command. Personal and group dynamics of other SEAL teams may be different than those of SEAL Team One resulting in different approaches to physical training while on prolonged submarine missions. Differences in command leadership as well as mission duration, objectives and requirements could have significant impact on the degree of deconditioning following a prolonged submarine mission. Furthermore, differences in the submarine platform could significantly impact the working and living conditions of the SEAL team and lead to different outcomes on mission related performance. For example, when compared to a converted ballistic missile submarine the fast attack submarine contains significantly less space for berthing and exercise equipment. Consequently, prolonged missions aboard a fast attack could potentially

have more of a negative impact on SOF mission related performance than that noted in the present study.

POSSIBLE STRATEGIES FOR MITIGATING DECONDITIONING

Since any factor that potentially impacts mission success is a major concern for Special Operations Forces, countermeasures should be sought to maintain the physical fitness of SEALs during extended submarine deployments. Providing exercise equipment and structured training programs that permit SEALs to maintain on board exercise regimens of similar type, duration, frequency and intensity as land-based regimens may prove fruitful for avoiding aerobic and anaerobic deconditioning during prolonged submarine deployments. However, given the limited space for exercise equipment on board, especially in fast attack submarines, considerable ingenuity will be required in the design and implementation of these training regimens. In view of this it would be prudent to explore new recent technologies for maintaining or even improving the physical fitness of SEALs while onboard the submarine. One such new technology that shows promise for improving aerobic endurance is respiratory muscle training. This training requires little equipment, can be performed by multiple people at the same time and can be easily conducted in the confined space of a submarine. Current research indicates that submaximum endurance capacity can be improved by as much as 50% after 4 weeks of respiratory muscle training (Boutellier and Piwko, 1992; Boutellier et al., 1992). As a side benefit those individuals who had been shown to retain CO_2 during heavy exercise significantly reduced their $P_{ET}CO_2$ following respiratory muscle training. This reduction in $P_{ET}CO_2$ has important implications for SOF diving missions where high CO_2 levels have been found to increase the risk of decompression illness (Hodes & Larrabee, 1946), oxygen toxicity (Lanphier, 1955, 1963; Lanphier & Camporesi, 1993) and the loss of consciousness underwater (Lanphier, 1980, 1988; Morrison et al., 1978; Warkander et al., 1990).

CONCLUSIONS AND RECOMMENDATIONS

- SEALs on submarine deployment tend to exercise less than their counterparts remaining at their home command.
- The decrease in running performance and the suggestion of slower heart rate recovery profiles of US Navy SEALs following a 33-day submarine deployment indicate that prolonged confinement aboard a submarine can lead to aerobic deconditioning.
- Decreases in the SEALs step test performance suggest that activities that require anaerobic bursts may also be impaired following a prolonged submarine deployment.
- Some of the observed decrements in aerobic and anaerobic performance of the DST may have been due to the combined effects of jet-lag and circadian asynchrony as a result of traveling from Korea to Hawaii immediately before conducting the post-tests.

- For the DST shooting performance, gross manual dexterity, muscular strength and muscular endurance and cognitive function were not significantly affected by the 33-day submarine deployment.

- There were significant increases in medical complaints for sinuses, headaches, backaches, constipation, and cuts/sores during the deployment for the deployed SOF unit.

- The submarine deployment has a significant negative affect on the SEAL's mood

- It is unknown to what level the observed degree of deconditioning will impact the SEALs performance during an actual mission; however, it can be inferred from the results that mission-related performance will be most impacted during and immediately following extended periods of high intensity physical exertion.

- Mission elements that require the SEAL to recover quickly and react following periods of heavy exertion may be compromised by the delay in recovery time associated with aerobic deconditioning.

- Recommendations for mitigation of deconditioning effects include:
    - Providing a structured physical training program that can be conducted on board the submarine that permit the SEALs to engage in exercises of similar type, duration, frequency and intensity as their normal land-based exercise regimens.
    - Minimize the SEALs time aboard the submarine to that necessary to accomplish the mission.
    - Explore the use of new training technologies such as respiratory muscle training for maintaining or improving aerobic performance while on extended missions.

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APPENDIX A: SELF-REPORT ACTIVITY LOG

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

NAME ____________________

DATE ____________________

TIME COMPLETED ____________

SOCIAL SECURITY	TIME	JULIAN DATE	YEAR

INSTRUCTIONS:

1. Use a No. 2 lead pencil.
2. Do not use ink, ballpoint, or felt tip pen.
3. Make black marks that fill the circle.
4. Erase clearly any changes you make.
5. Make no stray marks on the form.
6. Fill only one circle per time.

EXAMPLES

INCORRECT

CORRECT

	0	1:	2:	3:	4:	5:	6:	7:
WORK								
EXERCISING								
EATING								
RECREATION								
SLEEPING								

	8:	9:	10:	11:	12:	13:	14:	15:
WORK								
EXERCISING								
EATING								
RECREATION								
SLEEPING								

	16:	17:	18:	19:	20:	21:	22:	23:
WORK								
EXERCISING								
EATING								
RECREATION								
SLEEPING								

APPENDIX B: SLEEP QUESTIONNAIRE

NSMRL SLEEP Inventory

(Please print)
Name____

1) Your age in years ___________ Height (inches) _____________ Weight (pounds) ________

2a) Marital status (check one): ☐ single ☐ married ☐ divorced ☐ separated ☐ widowed

2b) While on shore do you live with any children under age 5? ☐ yes ☐ no

3) How many years did you complete for each of the following, and did you graduate?

	Number of Years	Did You Graduate?
High School	_______________	☐ Yes ☐ No
Technical School	_______________	☐ Yes ☐ No
College	_______________	☐ Yes ☐ No

4a) What is your rank and rate? ____

4b) Briefly list your principle duties ____

____
__

4c) On how many different occasions have you been transported on a submarine ?______________

4d) What is the average amount of time (days) you spend on a submarine per operation

5 How long have you been in the Navy? __________ years, _________ months

6) Do you consider your work activities to be (please check one):

☐ Very hard physical work

☐ Heavy physical work

☐ An average load of physical work

☐ Light physical work

☐ Very light physical work

7a) When at sea on a submarine how many hours (on average out of 24 hours) do you spend

working ________ training ________ exercising ________ sleeping

7b) On average, how many hours sleep do you get per 24 hours when

At Sea ________ On an Operation_____ At Home ________ On Leave ________

8) How often are you sick enough to see a member of the medical staff? (Check one)

☐ two or more times a year ☐ about once a year ☐ about once every two years ☐less than every two years

9) Do you have any medical condition that affects your sleep? ☐ yes ☐ no

10) Do you have another job while on shore for additional income? ☐ yes ☐ no

11) How often do you use the following when on an operation . . . check one space for each item listed below.

ITEM	Every day	More than once a week	About once a week	About once a month	Never or Almost Never
Aspirin or equivalent					
Antacids					
Laxatives					
Cough and cold medicines					
Sleeping pills					
Antihistamines (Benadryl)					
Caffeine tables					
Other medicine or drugs (please specify below)					

12a) How many cups/cans do you typically drink on operations per 24 hours? Check one space for each item listed.

	More than 5	3 to 5	1 or 2	Less than 1	None
Coffee					
Tea (caffeinated)					
Cola (caffeinated)					

12b) How many cups/cans do you typically drink when on-duty ashore? Check one space for each item listed.

	More than 5	3 to 5	1 or 2	Less than 1	None
Coffee					
Tea (caffeinated)					
Cola (caffeinated)					

12c) How many cups/cans do you typically drink when on liberty? Check one space for each item listed.

	More than 5	3 to 5	1 or 2	Less than 1	None
Coffee					
Tea (caffeinated)					
Cola (caffeinated)					

13) Do you smoke tobacco? ☐ yes ☐ no

If yes, how much do you smoke per day on the average? (Enter number)

How many cigarettes per day? _______ How many cigars per day? _______

Do you use chewing tobacco? ☐ yes ☐ no Dip tobacco? ☐ yes ☐ no

How often?_____________________________ How often?__________________

14) When at sea, how <u>physically</u> tired do you usually feel while on the submarine?

☐ Not at all ☐ A little ☐ Quite a bit ☐ Extremely

15) When at sea, how <u>mentally</u> tired do you usually feel while on the submarine ?

☐ Not at all ☐ A little ☐ Quite a bit ☐ Extremely

16) When at sea, how <u>tense</u> do you usually feel while on the submarine?

☐ Not at all ☐ A little ☐ Quite a bit ☐ Extremely

17) How often do you nod off when you should be alert while on the submarine?

☐ Never ☐ Rarely (1 or 2 times) ☐ Occasionally (4 or 5 times) ☐ Frequently

18) Please complete the following statement for days when you are home on several days leave:

I usually go to sleep at _____ AM/PM (circle one) and get up at _______ AM/PM (circle one). For additional sleep hours, if any, I usually go to sleep at ______ AM/PM (circle one) and get up at ______ AM/PM (circle one).

19) Do you nap even when you do not feel very tired? ☐ yes ☐ no

20) Some people feel older or younger than the age they are. How old do you feel? _________ (years)

21) You wish to be at your peak performance for an important test which you know is going to be mentally exhausting and which lasts for two hours. You are entirely free to plan your day. Which one of the following times would you choose to take the test? (Check one box)

- ☐ 8:00 - 10:00 AM
- ☐ 11:00 AM - 1:00 PM
- ☐ 3:00 - 5:00 PM
- ☐ 7:00 - 9:00 PM

22) Ideally, how many hours of sleep would you like to get on most days ?____________

Key for questions 23 - 36	
Never - once or twice in lifetime	Often - once or twice a week
Rarely - once or twice a year	Frequently - three or four times a week
Sometimes - once or twice a month	Always - five times a week or more

23) **How often do you have difficulty falling asleep?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

24) **How often after falling asleep, do you waken early and can't get back to sleep again?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

25) **How often do you have difficulty waking up?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

26) **How often do you have difficulty getting out of bed?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

27) **How often do you feel overly tired when awake?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

28) **How often do you take naps?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

29) **How often do you have difficulty staying awake?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

30) **How often do you have restless sleep or disturbing dreams or nightmares?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

31) **How often after falling asleep do you wake up by yourself and go back to sleep?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

32) **Do you usually feel well rested after you wake up and get out of bed?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

33) **How often do you suffer from digestive problems such as indigestion, heartburn, constipation, diarrhea, and/or cramps?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

34) **How often do you suffer from headache?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

35) **Do you feel as though you are getting enough sleep?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

36) **How often do you find yourself unable to concentrate on what you are doing?**

At Sea on sub	Never	Rarely	Sometimes	Often	Frequently	Always
On Operations	Never	Rarely	Sometimes	Often	Frequently	Always
Working Ashore	Never	Rarely	Sometimes	Often	Frequently	Always
On Leave	Never	Rarely	Sometimes	Often	Frequently	Always

APPENDIX C: PROFILE OF MOOD STATES

NSMRL MOOD SCALE

SOCIAL SECURITY NO

0 1 2 3 4 5 6 7 8 9

DATE

MONTH	DAY	YEAR
Jan		
Feb		
Mar	0	0
Apr	1	1
May	2	2
June	3	3
July	4	4
Aug	5	5
Sept	6	6
Oct	7	7
Nov	8	8
Dec	9	9

MARKING INSTRUCTIONS

- Use a No. 2 pencil only.
- Do not use ink, ballpoint, or felt tip pens.
- Make solid marks that fill the response completely.
- Erase cleanly any marks you wish to change.
- Make no stray marks on this form.

CORRECT: ● INCORRECT:

For each statement below please indicate how you felt in ***the last 24 hours****. We have labeled the two extremes,and the middle point, but your response could be anywhere within those extremes. For each statement darken one circle that indicates how much you agree or disagree with that statement..*

	Strongly Agree	Neither agree or disagree	Strongly Disagree
1. I was energetic.			
2. I was irritated.			
3. I was active.			
4. I was tired.			
5. I was tense.			
6. I was depressed.			
7. I was content (satisfied).			
8. I was in physical discomfort.			
9. I was stressed.			
10. I was frustrated.			
11. I was nervous.			
12. I was discouraged.			
13. I was annoyed.			

APPENDIX D: HEALTH SYMPTOMS QUESTIONNAIRE

Deployment Assessment Medical Questionnaire

NAME ____________________

Date Completed ____________________

Please indicate if you experienced the following physical health symptoms over the **PAST WEEK**:

	NO	YES: A Little	YES: Often	YES: Very Often
Flu	0	1	2	3
Head Cold	0	1	2	3
Sinus Trouble	0	1	2	3
Sore Throat	0	1	2	3
Difficulty Swallowing	0	1	2	3
Headache	0	1	2	3
Back Problems	0	1	2	3
Allergies	0	1	2	3
Stomach/Intestinal Upset	0	1	2	3
Muscle Aches or Cramps	0	1	2	3
Aching Joints and Bones	0	1	2	3
Constipation	0	1	2	3
Skin Rash	0	1	2	3
Eye/Ear/Nose Problem	0	1	2	3
Chills/Fever	0	1	2	3
Hoarseness	0	1	2	3
Heart Problems	0	1	2	3
Weight Loss/Gain	0	1	2	3
Dizziness	0	1	2	3
Cuts/Sores	0	1	2	3
Injury (Specify)	0	1	2	3
Other (Specify)	0	1	2	3

APPENDIX E: WALTER REED ARMY INSTITUTE OF RESEARCH REPORT ON SLEEP PATTERNS DURING OPERATION FOAL EAGLE

U.S. ARMY MEDICAL RESEARCH AND MATERIEL COMMAND

An Objective Evaluation of Quantity and Quality of Sleep as Determined by Wrist Actigraphy in U.S. Navy Special Warfare Personnel during Operation Foal Eagle

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ABSTRACT

The goal of the study was to determine performance effects of extended exposure to the submarine environment on U.S. Navy Special Warfare Personnel (i.e., SEALs) deployed on Operation Foal Eagle compared with that of U.S. Navy SEAL and Submariner control groups. As a central component of this study, a collaborative effort between the Walter Reed Army Institute of Research (WRAIR) and the Naval Submarine Medical Research Laboratory was established to field Actigraphs to assess sleep quantity and quality. The WRAIR Actigraph is a wrist-worn device that continuously records movement activity as a correlate of sleep quantity and quality. These devices were worn by 9 non-deployed SEALS (NDST), 10 deployed SEALs (DST) and 12 submariners (SCG) both before and during Operation Foal Eagle. The results from the actigraph data showed that the DST obtained significantly less total sleep per 24hr cycle (Total Sleep) during the early phase of the patrol (while in transit) than during the late phase (during operations) of the patrol ($p<0.01$). The main period of sleep per 24hr cycle (Main Sleep) for the DST was significantly longer during the late patrol (7.7 hours) phase than during either the pre-patrol (5.8 hours; $p<0.05$) or early patrol (4.0 hours; $p<0.01$) phases. There were no significant differences in the amount of Main Sleep or Total Sleep per 24-hr cycle between patrol phases for either the SCG or the NDST. An average of 8 hours per night sustains cognitive performance and the ability to comprehend, interpret, adapt and plan in rapidly changing circumstances. The DST in this study did not get adequate sleep during the pre-patrol and early patrol phases. Our recommendation is that operational commanders should develop effective sleep management plans and aggressively communicate to operators the impact of sleep deficits on individual and unit performance.

INTRODUCTION

The Departments of Operational Stress Research, Neurobiology & Behavior, and Biomedical Assessment, Division of Neuropsychiatry (Div NP), Walter Reed Army Institute of Research (WRAIR) collaborated with the US Naval Submarine Medical Research Laboratory (NSMRL) to evaluate sleep in deployed and non-deployed SEALs and Submariners based in Hawaii. During this study, WRAIR personnel evaluated sleep in Naval Special Operators' by using wrist-worn actigraphs. An actigraph is an unobtrusive device usually worn on the non-dominant wrist which continuously records arm movement from which sleep periods may be derived. In the laboratory, sleep and wakefulness are scored on the basis of concurrent recordings of electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG) signals; termed polysomnography (PSG). However, PSG is labor and equipment intensive, intrusive, and not practical for long term, ambulatory field studies. Actigraphy, on the other hand, is unobtrusive and efficient for monitoring sleep objectively, and has been shown to correlate highly with PSG-scored sleep/wake states.

Div NP, WRAIR built its first actigraph in 1974 and has led the way in actigraph development. Since 1984, Div NP and Precision Control Design, Inc. (PCD, Inc.), have successively fielded smaller, more robust, more powerful devices to measure sleep under operational conditions such as (a) in soldiers undergoing Ranger training (Pleban et al., 1990), (b) during rotations through the National Training Center (NTC), (c) in studies examining the efficacy of sleep-inducing medication during trans Atlantic troop deployment by air (Penetar et al., 1989), and (d) in studies of sleep/wake schedules of sailors engaged in solo trans Atlantic races (Stampi & Broughton, 1989).

Adequate sleep is important for effective performance. Sleep loss degrades cognitive performance, causing impairment in the ability to comprehend, interpret, adapt and plan in rapidly changing circumstances (Belenky et al., 1994). The cumulative effects of restricted sleep schedules is loss of productivity, leading ultimately to accidents and catastrophes (Mitler et al., 1988). In the Gulf War (Operation Desert Shield/Storm), sleep deprivation was a contributing factor in motor vehicle accidents, the largest source of injury and death for U.S. Army personnel (LTC Gordon D. Griffith, U.S. Army Safety Center, 3 June, 1994, personal communication to COL Gregory Belenky). Sleep deprivation was also a contributing factor in incidents of friendly fire described by Belenky et al. (1996). The information obtained from our actigraph measurements will assist Naval Special Operation Commanders in sustaining and enhancing Naval Special Operation performance, effectiveness, and survivability during special operations, unconventional warfare, clandestine operations and combat.

OBJECTIVES

The primary purpose of the actigraph portion of the study was to provide the Naval Special Warfare Command with data pertaining to sleep quantity and quality of deployed Naval Special Warfare units during Operation Foal Eagle.

The secondary purpose was to demonstrate to the Naval Special Warfare community and the larger military community the utility, reliability, durability, and unobtrusiveness of wrist actigraphy for measuring sleep in personnel in operational environments.

METHOD

Subjects

All subjects were recruited from SDV Team One and the USS Kamehameha SSN 642, as described in the Main Report. Pre-deployment and deployment actigraph data were obtained for all subjects. The participants in this study were classified in three groups as follows: the Non-deployed SEAL Team (NDST), the Deployed SEAL Team (DST), and the Submariner Control Group (SCG).

Equipment

The BMA-32 actigraph manufactured by PCD, Inc., Ft. Walton Beach, FL, was used in this study. This unit contains 32K of random access memory (RAM) and is capable of collecting and storing data for up to 14 days. The actigraphs were set to zero-crossing mode in which the movement activity signals are compared against a specified threshold and a count recorded whenever the signal crosses the threshold. Cumulative counts of one-minute duration were chosen to maximize the discrimination of sleep from wake states.

Procedure

Data were retrieved from each participant's actigraph approximately every 11 days to prevent exceeding the data storage capacity (see Equipment section above). Data were downloaded from the actigraph to a secure-access database approximately six times per participant. After each download, the actigraph battery was replaced with a fresh one and the actigraph re-initiated and returned to the participant. Each participant wore the same actigraph originally issued to him during the entire study.

Actigraph Data

Data collected from the study were transferred to 3 ½" disks for transport to the Department of Biomedical Assessment for processing and analysis and was always under the personal control of a member of the WRAIR research team.

Data clearly indicating that the actigraph was worn and recording during sleep periods were noted in the analysis of sleep parameters. Sleep periods which contained epochs during which the actigraph was not worn or where artifacts were detected, were excluded from data analyses.

The following four categories of sleep data were determined from the actigraph records:

(1) Main Sleep amount recorded during the longest period of sleep taken during a 24hr cycle
(2) Total Sleep amount in a 24hr cycle
(3) Number of Awakenings during the Main Sleep period
(4) Total Wake Time during the Main Sleep period

Main Sleep amount is the longest period of sleep taken during a 24hr cycle. Total Sleep amount in a 24hr cycle includes Main Sleep and naps that may have been taken in this 24hr cycle. Main and Total Sleep amounts are measures of *sleep quantity*, whereas the Number of Awakenings and Total Wake Time during the Main Sleep period are measures of *sleep quality*.

The Number of Awakenings is the number of times movement activity within the main sleep period was of sufficient magnitude and duration to be considered awake episodes. The Total Wake Time during the Main Sleep period is the sum of all of the time spent in each awakening during main sleep in the 24-hr cycle.

See Figure 1 for an example of sleep/wake determinations and awakenings.

Sample Actigraph Record

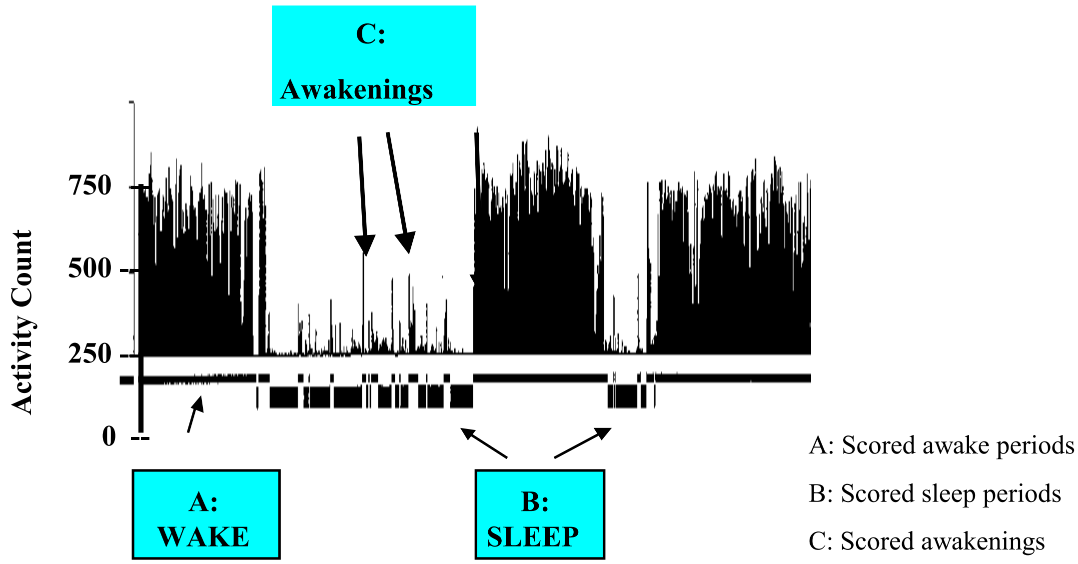


Figure 1. Sample actigraph record and corresponding sleep/wake scoring. Awakenings take away from Main Sleep time. This sample of an actigraph record clearly distinguishes these periods.

The data were separated into pre-deployment and deployment phases. The pre-deployment phase data were collected prior to the submarine deployment and will be referred to as Pre-Patrol data. The deployment phase data were further divided into two time periods: an Early Patrol phase (transit time) and a Late Patrol phase (operations).

RESULTS

Since the number of days each participant contributed to the data set varied, each participant was given equal weighting by taking the average of all his sleep data for each phase, i.e., Pre-Patrol, Early Patrol, and Late Patrol. The processed actigraph data were analyzed statistically using an analysis of variance (*ANOVA)* for each of the measures of Main Sleep and Total Sleep, as well as Number of Awakenings and Total Wake Time during the Main Sleep period. Post-hoc comparisons among means were conducted using the Tukey/Kramer procedure. Results for the Non-deployed SEAL Team (NDST), Deployed SEAL Team (DST), and Submariner Control Group (SCG) are presented below.

Table 1 shows the number of participants in each group with analyzable data and summarizes the sleep data (i.e., the hours of sleep during the Main Sleep period and the Total Sleep per 24-hr cycle) for all groups during each of the three patrol phases.

Table 1. **Main and Total Sleep (Hours) During Pre-, Early and Late Patrol**

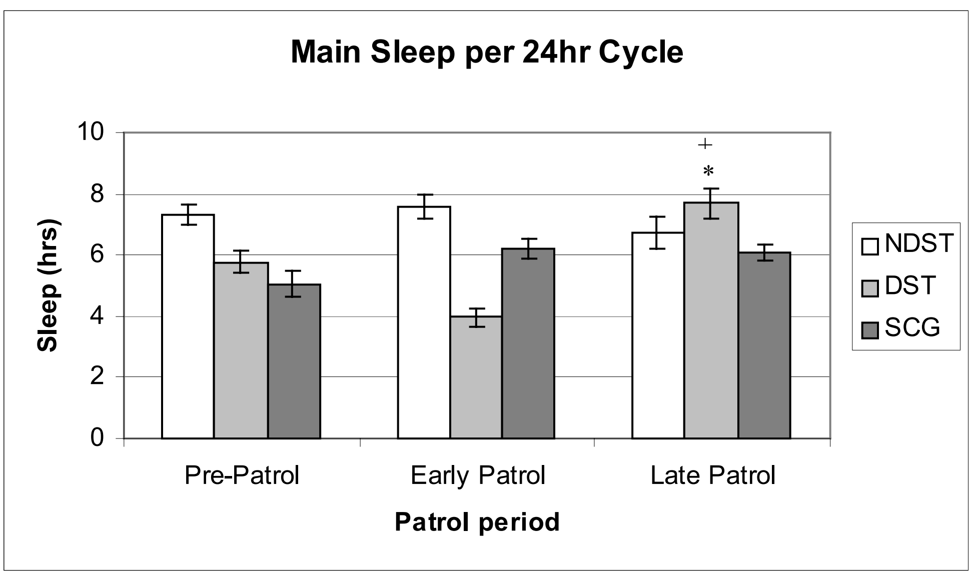
		Patrol Phases			
	n	**Pre-Patrol**	**Early Patrol**	**Late Patrol**	**Significance**
Non-Deployed SEAL Team (NDST)	8				
Main Sleep Per 24hr Cycle		7.3 hrs (sem=0.32)	7.6 hrs (sem=0.39)	6.7 hrs (sem=0.51)	No difference
Total Sleep (Main Sleep + Naps) per 24hr Cycle		7.7 hrs (sem=0.39)	8.4 hrs (sem=0.50)	7.5 hrs (sem=0.55)	No difference
Deployed SEAL Team (DST)	10				
Main Sleep Per 24hr Cycle		5.8 hrs (sem=0.34)	4.0 hrs (sem=0.28)	7.7 hrs (sem=0.49)	Pre vs Late p<0.05; Early vs Late p<0.01
Total Sleep (Main Sleep + Naps) per 24hr Cycle		6.5 hrs (sem=0.27)	5.2 hrs (sem=0.46)	8.4 hrs (sem=0.38)	Early vs Late p<0.01
Submariner Control Group (SCG)	12				
Main Sleep Per 24hr Cycle		5.1 hrs (sem=0.40)	6.2 hrs (sem=0.35)	6.1 hrs (sem=0.25)	No difference
Total Sleep (Main Sleep + Naps) per 24hr Cycle		5.7 hrs (sem=0.41)	6.5 hrs (sem=0.31)	7.2 hrs (sem=0.26)	No difference

Main Sleep: Results from the Main Sleep per 24hr Cycle indicated that there were significant differences in the amount of Main Sleep obtained between groups ($F_{2,27} = 10.63$, $p=0.0005$) and across patrol phases ($F_{2,56} = 5.41$, $p=0.0075$), with a significant overall Group x Phase interaction ($F_{4,83} = 12.52$, $p<0.0001$). Specifically, of the three groups during the Pre-Patrol phase, the NDST obtained substantially more Main Sleep at 7.3 hours than the DST at 5.8 hours and the SCG at 5.1 hours. The difference in sleep quantity between the NDST and the SCG was statistically significant ($p < 0.01$); that is, the NDST obtained significantly more sleep than the SCG during Pre-deployment. Although the NDST obtained more Main Sleep than the DST, this difference was not significant, nor was there any significant difference in the Main Sleep amount between the DST and the SCG during the Pre-Patrol phase. During the Early Patrol phase, the NDST and the SCG did not differ from each other in the amount of Main Sleep obtained (7.6 hours and 6.2 hours, respectively), but both obtained significantly more sleep (both at $p < 0.01$) than the DST (4.0 hours). There were no significant differences in the amount of Main Sleep among the three groups (range = 6.1 to 7.7 hours) during the Late Patrol phase of the operation. Across patrol phases, the DST was the only group with significant differences in the amount of Main Sleep obtained across the three phases of the operation. The amount of Main Sleep obtained during the Late Patrol by the DST (7.7 hours) was significantly higher than that obtained during either the Pre-Patrol phase (5.8 hours; $p<0.05$) or the Early Patrol phase (4.0

hours; $p<0.01$), however there was no significant difference in Main Sleep amount obtained during Pre-Patrol and Early Patrol.

Total Sleep: Deficits in normal daily sleep quota can be compensated for by taking naps if and when opportunity permits. This is reflected in Total Sleep per 24-hour cycle, in which all three groups in all phases of the study showed additions to their Main Sleep obtained per 24-hour cycle. Results from the Total Sleep per 24hr Cycle measurement indicated that there were significant differences in the amount of Total Sleep obtained between groups ($F_{2,25} = 7.58$, $p=0.003$) and across patrol phases ($F_{2,52} = 5.93$, $p=0.0051$), with a significant overall Group x Phase interaction ($F_{4,77} = 6.48$, $p=0.0003$). Specifically, while NDST's Total Sleep (7.7 hours) was longer than either the DST's (6.5 hours) or the SCG's (5.7 hours), there were no statistical significant differences between groups in the Total Sleep measurement during the Pre-Patrol phase. There were also no significant differences between groups for Total Sleep during the Late Patrol phases (range = 7.2 to 8.4 hours). During the Early Patrol phase, the NDST obtained significantly more Total Sleep (8.4 hours) than the DST (5.2 hours; $p<0.01$). There were no significant differences in the Total Sleep obtained between the NDSR and the SCG nor between the DST and the SCG during this phase. Across patrol phases, the DST showed no significant differences in the amount of Total Sleep obtained during the Pre-Patrol and the Early Patrol. However, the DST showed a significant increase ($p<0.01$) in the Total Sleep obtained during the Late Patrol (8.4 hours) in comparison to the Early Patrol phase (5.2 hours). There were no significant differences across patrol phases for either the NDST or the SCG. There was an increase in "nap" length (1.2 hours) during the Early Patrol phase that substantially contributed to the Total Sleep for the DST.

Figures 2 and 3 show the comparisons of the three groups, respectively, for Main Sleep and for Total Sleep in 24-hour cycles.



*

Figure 2. Number of sleep hours during Main Sleep per 24hr Cycle for each study group as determined by Actigraphy. NDST = Non-deployed SEAL Team; DST = Deployed SEAL Team; SCG = SEAL Control Group. * = significant from Pre-Patrol; + = significant from Early Patrol. Error Bars represent ± SEM

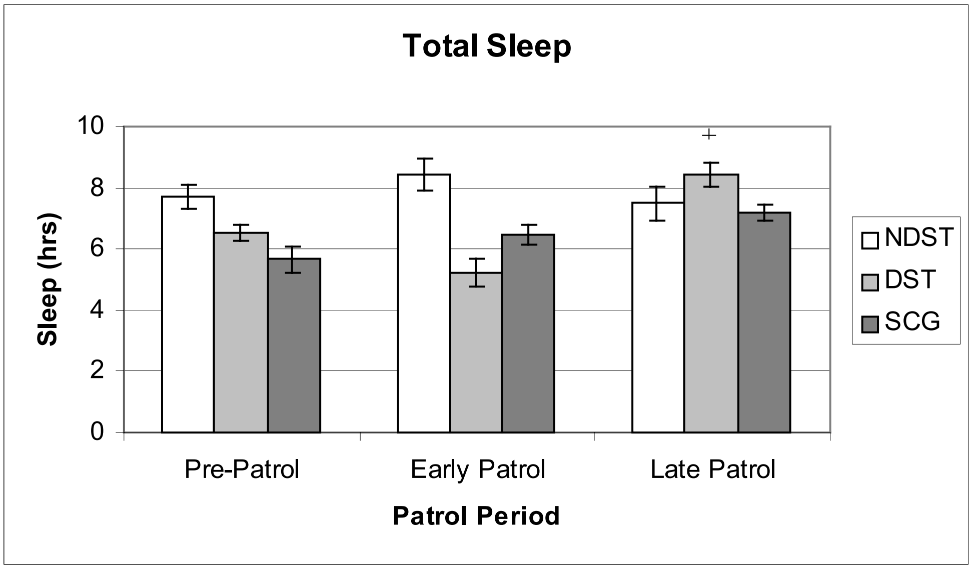


Figure 3. Number of sleep hours during Total Sleep per 24hr Cycle for each study group as determined by Actigraphy. NDST = Non-deployed SEAL Team; DST = Deployed SEAL Team; SCG = SEAL Control Group. + = significant from Early Patrol. Error Bars represent ± SEM

Measures of sleep disruptions are obtained both in terms of average Number of Awakenings and average Total Wake Time during the Main Sleep period for each group. These results are presented in Table 2.

Number of Awakenings and Total Wake Time during Main Sleep: There were no significant differences in the Number of Awakenings nor Total Wake Time during Main Sleep between groups and across patrol phases, with no significant overall Group X Phase interactions. The NDST had the greatest Number of Awakenings (11.7) as well as the longest Total Wake Time during the Main Sleep period (57.4 minutes) in the Pre-deployment phase, while the SCG had the least Number of Awakenings at 7.3 and the shortest Total Wake Time during the Main Sleep period at 44.8 minutes. The DST had 10.8 awakenings for a Total Wake Time of 56.6 mins. During the Early Patrol phase, the DST and SCG showed a comparable Number of Awakenings and Total Wake Times during the Main Sleep period as that seen in the Pre-Patrol phase. However, the Number of Awakenings and Total Wake Time decreased (but was not significant) for the NDST during this same phase. During the Late Patrol phase, Number of Awakenings and Total Wake Time decreased (but not significantly) for the NDST and DST. Number of Awakenings for the SCG increased slightly but decreased in the Total Wake Time from that seen in the prior two phases. These comparisons are shown graphically in Figure 4 for Number of Awakenings and in Figure 5 for Total Wake Time during the Main Sleep period.

Table 2. **Number of Awakenings and Total Wake Time during Main Sleep**

		Patrol Phases			
	n	**Pre-Patrol**	**Early Patrol**	**Late Patrol**	**Significance**
Non-Deployed SEAL Team (NDST)	8				
Number of Awakenings		11.7 (sem=1.80)	10.2 (sem=2.12)	9.6 (sem=1.74)	No difference
Total Wake Time		57.4 mins (sem=8.60)	45.8 mins (sem=10.56)	39.5 mins (sem=8.33)	No difference
Deployed SEAL Team (DST)	8				
Number of Awakenings		10.8 (sem = 1.47)	10.6 (sem=1.83)	9.3 (sem=1.23)	No difference
Total Wake Time		56.6 mins (sem=5.01)	61.0 mins (sem=16.86)	43.0 mins (sem=9.92)	No difference
Submariner Control Group (SCG)	12				
Number of Awakenings		7.3 (sem=0.83)	7.6 (sem=1.65)	8.2 (sem=2.14)	No difference
Total Wake Time		44.8 mins (sem=13.13)	45.2 mins (sem=10.22)	35.5 mins (sem=2.03)	No difference

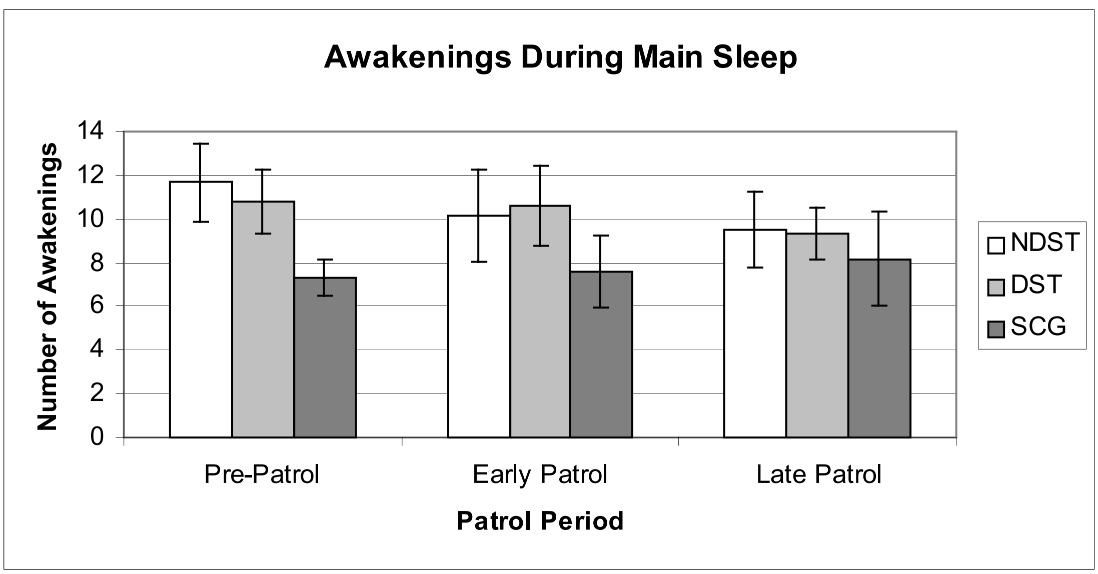


Figure 4. Number of Awakenings during Main Sleep per 24hr Cycle for each study group as determined by Actigraphy. NDST = Non-deployed SEAL Team; DST = Deployed SEAL Team; SCG = SEAL Control Group. Error Bars represent ± SEM

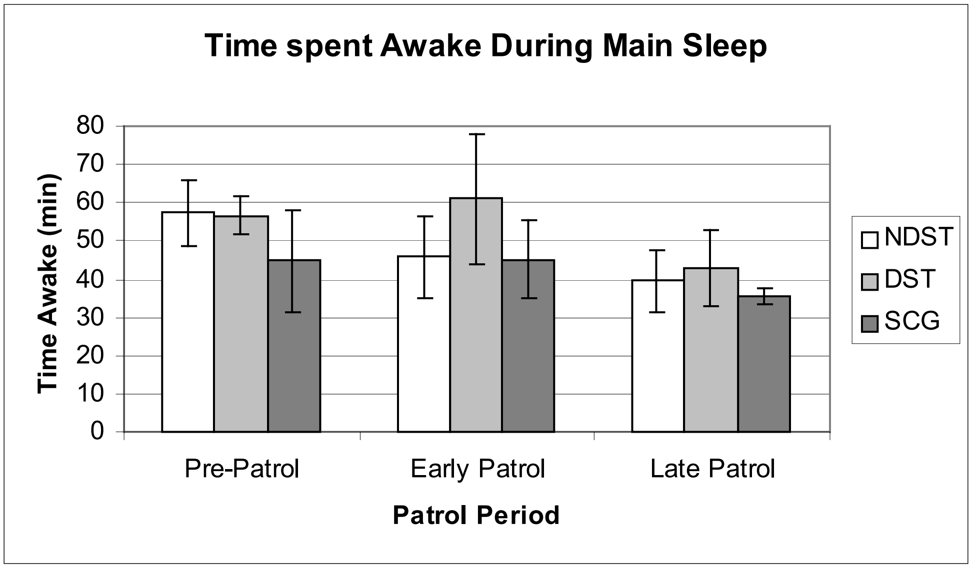


Figure 5. Number of minutes spent awake during the Main Sleep per 24hr Cycle for each study group as determined by Actigraphy. NDST = Non-deployed SEAL Team; DST = Deployed SEAL Team; SCG = SEAL Control Group.

DISCUSSION

The results of the actigraph data analysis show that the NDST, with Main Sleep averaging 7.3 hours during Pre-Patrol and 7.6 and 6.7 hours during Early and Late Patrol phases, obtained the most sleep when compared with the DST and the SCG. The amount of sleep recommended by the National Sleep Foundation (1998) is 8 hours as the minimum necessary to sustain alertness and optimal cognitive functioning throughout the awake period. The actigraph data suggest that the stable work environment of normal 8 hours daytime duty with no additional duty demands may have permitted the opportunity for adequate sleep for the NDST. Consequently, Main Sleep and Total 24 hr Sleep were better regulated and resulted in both longer duration and greater continuity of sleep. Both the DST and the SCG, because of their unusual work loads and varying work schedules in preparation and training for the Deployment (Pre-Patrol) and the demands exacted by mission requirements during Deployment (Early and Late Patrol), may not have had regular sleep schedules. The Main Sleep recorded by the actigraph was less than 6 hours during Pre-Patrol and less than 5 hours during the Early Patrol (for the DST). The Total Sleep recorded by the actigraph was 6.5 hours or less during Pre-Patrol and Early Patrol. Both clearly indicate daily sleep deficits and mounting sleep debt from the on-going sleep deprivation. However, the impact of less than optimal sleep on operational performance is unknown. Although the cognitive test battery showed no significant changes in cognitive performance in either the DST or the SCG following the deployment it may be that the tests in the cognitive test battery were not sensitive enough to detect the decrements associated with sleep deprivation. Alternatively, some of the sleep deprivation from the pre-deployment

and early deployment phases may have been offset by increased sleep during the late deployment period.

Naps are indicative of the need for compensatory sleep following any sleep deprivation and naps may mitigate the decline in performance. Actigraph data suggested that the NDST, DST, and the SCG alike compensated for less than adequate Main Sleep periods by taking naps.

Awakenings during sleep periods, whether spontaneous or due to external stimuli result in loss of sleep. The cumulative effect of even brief awakenings can be detrimental to next day performance (Belenky et al., 1994). Sleep fragmentation, defined as the number of awakenings and duration of these awakenings, is a matter of concern for both the DSTs and SCGs. Fragmentation reduces total sleep duration, a factor determining next day performance. The amount of sleep lost from the awakenings for these two deployed groups is equivalent to that lost by the non-deployed group (NDST). However, the latter had the opportunity for longer sleep periods and thus acquired greater sleep amounts. The less than ideal sleep environment for both the DST and the SCG may well have precluded opportunities for adequate sleep.

As is true of the larger study, care must be taken when interpreting this actigraph study in the context that it was conducted on a single submarine unit with SEALs and Submariners from one command.

Safety, welfare and effective performance are issues of paramount importance for all military personnel. The cases cited in this report for the rangers, combat soldiers, truckers, and other workers, all of whom were experiencing sleep deprivation, offer compelling evidence for mandating sleep discipline. This discipline would include the requirement of daily adequate sleep quantity (8 hours) and quality (minimal sleep fragmentation) not only to maintain effective operational performance, but also to ensure the welfare of all personnel.

The parameters of training in the military are designed to hone the combat edge of individuals and units. This training process must provide participants with tough, realistic training that will prepare them for war. During this process, training conditions must place participants under conditions that stress them physically, intellectually, and emotionally. While exposed to severe environment training conditions, and physically and emotionally challenged by time constraints, the safety parameters of training must always be considered. Sleep loss is a reality of training and has been documented to be a reality of war. Sleep research affords the opportunity to increase leadership understanding, individual safety, and performance in a minimally invasive and scientifically appropriate manner. Actigraph research assists commanders in understanding the impact of sleep on training performance and safety, and provides them insight into the amount of sleep required for individuals and units to remain combat effective. Research on sleep enhances the Commander's ability to hone the combat edge of their units thereby keeping the U.S. Armed Forces the best-trained combat force in the world.

LIMITATIONS

There were some limitations to use of actigraphy in the current study. In the submarine, an unanticipated saturation of the activity signal occurred as a consequence of submarine vibrations during certain portions of the operation. These vibrations resulted in rejection of actigraph data from the analysis due to uninterpretable results. Nevertheless, we were able to ensure adequate sampling of data from most subjects to attain reliable results between subjects and across patrol

phases. A solution to this motion artifact problem is under development. Reconciliation of differences in sleep quantity between self-report logs (see Main Report) and objective actigraph data may be required in future studies using the motion artifact suppression devices.

Additional limitations of the use of actigraphs in this setting relate to the design of the device worn. The matchbox sized, rectangular design was viewed as a hindrance to some of the operations performed by the personnel (e.g., when parachuting or packing the parachutes). Some participants were concerned that the edges of the device would potentially interfere with other normal work activities. A related consideration is the bulkiness of the waterproofing box that must be secured around the actigraph (which is not currently waterproof) prior to the DST's immersion in the water. In development and testing is a watertight actigraph unit the size and thickness of a standard wristwatch with watch function capabilities, which will eliminate the waterproofing problem as well as the need to wear two wrist-worn devices.

CONCLUSIONS

The Main Sleep recorded by the actigraph was less than 6 hours during Pre-Patrol and less than 5 hours during the Early Patrol (for the DST). The Total Sleep recorded by the actigraph was 6.5 hours or less during Pre-Patrol and Early Patrol. Both clearly indicate daily sleep deficits and mounting sleep debt from the on-going sleep deprivation. Taking naps can compensate for inadequate sleep. In the case of the DST and SCG during Deployment, this strategy may have been used, resulting in their total daily sleep time exceeding 5 hours. Validation of these findings using an improved (i.e., artifact-eliminating) version of the actigraph is recommended.

The amount of sleep lost from the awakenings during the Main Sleep for the two deployed groups is equivalent to that lost by the NDST. However, the latter had the opportunity for longer sleep periods and thus acquired greater sleep amounts. The less than ideal sleep environment for both SEALs and Submariners may well have precluded opportunities for adequate sleep.

RECOMMENDATIONS

Operational Commanders should develop effective sleep management plans and aggressively communicate to operators the impact of insufficient sleep on individual and unit performance. Commanders should also encourage operators to sleep when time permits and does not interfere with mission accomplishment.

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